GUASTAVINO TILE CONSTRUCTION:
An Analysis of a Modern Cohesive Construction Technique

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INTRODUCTION

Large open volume spaces have always captured the interest and imagination of people and have provided a challenge to architects and engineers. This challenge is how to enclose a space without using a forest of columns and limiting the function of the space. Traditional gravity or bearing systems have served as the answer for many centuries but do not realize the full potential strength to mass ratio of the materials. The revival and further development of an ancient construction technique, cohesive or conglomerate construction, provided the opportunity to exploit the strength of similar materials. Cohesive construction "has for its basis the properties of cohesion and assimilation of several materials; which, by a transformation more or less rapid, resemble Nature's work in making conglomerates."[1]

Rafael Guastavino, an immigrant to the United States from Barcelona, Spain, in the late 19th Century, developed a modern cohesive construction technique, based in the tradition of Catalan masonry vaulting and utilizing layers of thin ceramic tiles and a portland cement mortar. His Guastavino Fireproof Construction Company was responsible for the promotion and construction of

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[1] Rafael Guastavino, The Theory and History of Cohesive Construction, 2nd ed. (Boston: Ticknor & Co., 1893), 45.

cohesive construction systems throughout the country. The Company's success led to the technique being known as "Guastavino Construction." A factor to the proliferation of the Guastavino construction was its compatibility with current aesthetic tastes such as the Beaux Arts.

This thesis traces the history and development of the Guastavino system, and discusses conservation issues relating to the applications of the technique. The first chapter covers Rafael Guastavino's educational and professional background, placing it in its historic Spanish and late 19th/early 20th Century United States context. The second chapter provides a comparison of cohesive construction with the more well known gravity-based system. Using that discussion as an overview, Guastavino's contributions to the further development of cohesive construction are examined in further detail. General conservation issues are discussed in the third chapter. The final chapter includes case studies of four Philadelphia buildings in which the condition of the Guastavino construction was surveyed and analyzed.

My research was aided by gaining access to buildings in the Philadelphia area and to the Guastavino Fireproof Construction Company archives, donated by the late George Collins, an architectural historian, at Columbia University. These archives, though uncatalogued, provide a wealth of primary source information on the technical and aesthetic development of the Guastavino system. Company-produced advertisements, construction photographs of projects and technical data on the construction technique and the different tiles make up one

part of the archives. The other portion is a collection of individual building files on projects that utilized Guastavino construction. Each file includes working drawings, a copy of the contract, correspondence and, in some cases, the specifications pertaining to the Guastavino construction and applications for payments.

Another valuable source of information was the work of George Collins -- in particular, his article published in the Journal of the Society of Architectural Historians.[2] This article traced the history of cohesive construction placing Guastavino's work within that context. The evolution of the system is shown through descriptions of projects built by the Guastavino Company. The technical aspects of the system are discussed in order to explain the unique properties of cohesive construction and the advancements which Guastavino developed.

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[2] George Collins, "The Transfer of Thin Masonry Vaulting from Spain to America," Journal of the Society of Architectural Historians 27 (October 1968)3:176-201.

CHAPTER ONE

HISTORICAL BACKGROUND

There are very few records giving any biographical data on Rafael Guastavino. The most complete source of this information is a series of articles by Peter Wight in The Brickbuilder.[3] The biographical sketch that follows is a summary of the details provided in these articles.

Rafael Guastavino y Moreno was born in 1842 in Valencia, Spain. He was brought up in a musical family and trained as a musician. Well schooled in the arts, at the age of seventeen Guastavino shifted his focus to the world of architecture. His first architectural job was as the assistant of D. Jose Nadal who at the time was the Royal Inspector of Public Works.[4] Guastavino's responsibilities acquainted him firsthand with the projects being built in his community during this time. He assisted with on-site inspections of building materials, structural integrity and construction techniques and quality. This training not only allowed him to gain knowledge in architectural design but also in construction, the latter of which was to play a valuable part in his career.

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[3] Peter B. Wight, "The Works of Rafael Guastavino. In Four Parts," The Brickbuilder (April, May, September, October 1901).

[4] Peter B. Wight, "The Works of Rafael Guastavino. Part I-As Architect," The Brickbuilder, April 1901, 79.

After a few years of this experience he relocated to Barcelona, where he entered the School of Architecture at the University. This era of architecture is unique for its necessity to quickly respond to both the stylistic changes and technological advances accompanying the Industrial Age. New materials and the associated opportunity for new construction techniques were emerging, with the most popular of these being the use of cast iron and concrete. Through his schooling and previous work experience, Guastavino had become interested in Catalan vaulting, a traditional construction method that incorporated principles similar to those of concrete construction. He was able to capitalize on this interest with the advent of new building types, such as large factories and railroad stations, which required large open volume spaces ideal for this construction method.

Guastavino's academic training was based in a strong, unique historical background. Spanish architecture of the period has been characterized as more conservative than other European architecture of the time, with less proliferation of the eclecticism of styles that typified late 19th century architecture.[5] 19th century Spanish architecture seems to have retained a close affinity for its earlier Moorish and Romanesque roots in both inspiration for ornamentation, design theory and to an extent construction techniques. Such influences can be seen even in Spanish Renaissance architecture and subsequent revival movements.

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[5] Sir Banister Fletcher, A History of Architecture, edited by John Musgrove, 19th edition (London: Butterworths, 1987), 1102.

As in the major Architectural schools across Europe, the Classical styles were still taught in Barcelona as the basis of architectural thought, but were tempered with the emergence of the quest for honesty of materials and structural expression in architecture which began to gain popularity in the mid-19th century. A brief look at the styles of the early to mid-19th century being taught and built in Spain provides a background context for the examination of Guastavino's work.

The Neo-Classical style with its pure symmetrical forms and basis in geometry was the most prominent style used during the first third of the 19th century. It was highly promoted by the Universities of Madrid and Valencia, with such success that it still influenced designs into the 1860s.[6] The decades between 1830 and 1850 saw a growing popularity of eclecticism, with the most diverse use of historic styles to date. From this, two directions emerged: one that continued to follow the Neo-Classical theories and the second that promoted a Gothic Revival with its medieval roots and emphasis on honesty in architectural structure and ornamentation. From 1850-1870, the Gothic Revival style became a more prominent style and, while Classical styles were still used, they were less austere and began to have detailing derived from the Renaissance Revival. The Second Empire and High Victorian styles popular elsewhere did not have as great an impact on Spanish architecture as a whole but rather elements and details were extracted and applied to other more traditionally styled buildings.

While a student Guastavino worked for the architects of Granell & Robert

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[6] Fletcher, 1102.

until 1862.[7] It was here that he was able to apply his previous work experience with his academic knowledge to the architectural profession. There is no record of the projects that Guastavino worked on while at Granell & Robert nor is it recorded how long he was associated with the firm. Also, there is no mention in Wight's articles of when and if he graduated from the University. There is however a record of his first built project in private practice, which was the result of a competition in 1866.[8] This residence is in keeping with the classical tastes of the day but looked back to the Renaissance in its massing and elements. All his residential work reflects this design philosophy while still acknowledging new construction technology. From early in his career, Guastavino was an experimenter with and promotor of modern technology, as can be seen in the use of English Portland cement for the construction of his own residence at Barcelona in 1872.[9]

Barcelona was evolving into a major manufacturing site and thus required such buildings as mills, large factories and storage warehouses. All of these buildings had fire-proof construction as a major necessity. It was with this in mind that Guastavino began further exploring the use of cements and concrete for not just the walls of a building but also for the roof and floor construction as well. Combining the careers of architect and builder, as was common in Spain at this

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[7] Wight, 79.

[8] Wight, 79. See Figure #1.

[9] Wight, 80. See Figure #2.

time, Guastavino had the advantage of being able to experiment with construction techniques and adapt the designs in accordance with the success or failure of these tests.

As precedents for his works, Guastavino had access to Spain's rich Byzantine and Romanesque building heritage, of which he made a thorough study. Parts of this study are discussed in a paper on Cohesive Construction that Guastavino read before the International Congress of Architects in Chicago in 1893. He found that "...The character of the most ancient Byzantine and Romanesque types in Spain was of monolithic construction, made of conglomerated material. The walls and floors (like other specimens relatively modern) were some of them, of stone and concrete, others concrete alone."[10] This study became the basis for his revival of ancient concrete construction techniques, adapting them to utilize modern technology.

One of his first opportunities to experiment with cohesive construction was the Batallo Factory in Barcelona of 1868-69. This building covering four blocks is said by Wight to have established his reputation as a skilled architect. The building incorporated two structural systems: long tile vaults with tie bars on heavy timber beams, themselves fire-resistent due to their massiveness, and, second, domical vaults on tile arches braced with iron tie rods.[11] With its

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[10] Wight, 80.

[11] George Collins, "The Transfer of Thin Masonry Vaulting form Spain to America," Journal of the Society of Architectural Historians 27 (October 1968)3:191.

innovative construction techniques and use of materials, this building attracted much attention from local architects and instructors from the School of Architecture. Guastavino determined that a critical element in this type of construction was the quality of cement used to make the mortar and concrete. It was the unavailability of a consistent high quality cement that was to prove most frustrating for Guastavino, and in fact eventually contributed to his decision to emigrate to the United States in 1881.

For the next twelve years after the completion of the Batallo Factory and until his emigration to the United States, Guastavino was to construct in Spain many mills, factories and warehouses, further experimenting with concrete and exploring its construction merits and fire-proof qualities. While the larger portion of his work in this period was utilitarian buildings, the population explosion and new wealth of the Barcelona area, also, provided him the opportunity to design apartment buildings, theaters and fashionable town residences for the main manufacturer barons. These latter projects challenged Guastavino to develop a certain refinement in the detailing and finishing of concrete. An example of his residential work showing this development is as a result of an unnamed competition in 1869. Giving the appearance of having stone details on its exterior, Guastavino created the ornamentation including the frieze and main cornice from cement. Another unique feature is the spiral staircase he constructed of concrete with marble treads.[12] In all of his projects, Guastavino

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[12] Wight, 81. See Figure #3.

exploited modern construction technology wherever it improved upon more traditional methods.

As previously mentioned, Guastavino was frustrated by the lack of consistent quality in building materials. He began to dicuss the possibility of emigrating to the United States which was touted as producing modern, quality products. About the same time, in the early 1870s, the United States was in the midst of preparations for the Centennial Exposition of 1876 to be held in Philadelphia. As part of the celebration an international call for architectural works was organized, and Guastavino was one of many foreign architects to send an entry. His submission of several projects, collectively titled "Improving the Healthfulness of Industrial Towns,"[13] received a medal of merit. As Spain did not receive a large number of awards, Guastavino was buoyed by his achievement. Hoping to capitalize on his success and to work with quality materials, he began to make serious plans to emigrate to the United States, which culminated in his arrival with his son, Rafael Guastavino y Esposito at New York in 1881.

Guastavino arrived with letters of introduction to several architects in the New York area, but found them to be hesitant about accepting the merits of cohesive construction. His experiments of cohesive construction in Spain had led to the development of a system for spanning large distances with vaults and domes utilizing only ceramic tiles and a cement mortar. This was an entirely different construction concept from the prevalent American traditions utilizing

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[13] Collins, 192.

post and beam bearing systems. As a result, Guastavino was unable to immediately establish himself as either an architect or builder. Instead, initially, he wrote and illustrated articles with original drawings for magazines, such as The Decorator and Furnisher, introducing traditional Spanish and other exotic architectural styles to the American public.[14] However, not giving up on his dream of further developing and promoting cohesive construction techniques, Guastavino also started a methodical study of American architectural tastes, construction traditions and available building materials. This study was to become part of the groundwork that led to him establishing the Guastavino Fireproof Construction Company in 1889.

Guastavino's first American break into design in 1883 when he won a competition for the Progress Club in New York City at 59th Street and 4th Avenue. Though he chose the Moorish style of early Spain for the building design, the construction system was based in American traditions.[15] He was asked to collaborate with Henry Fernbach, the expert advisor of the selections committee who had recommended that Guastavino's entry be chosen, but the final product was of Guastavino's design.[16] Working with Fernbach, a well established

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[14] Peter B. Wight, The Life and Works of Rafael Guastavino. Part III. The Practice of Architecture and Cohesive Construction in America," The Brickbuilder, September 1901, 184.

[15] See Figure #4.

[16] Wight, 185.

architect and early member of the American Institute of Architects,[17] Guastavino was able to gain entry and recognition into the circle of the architectural profession and make important contacts. Several opportunities came his way as a result of this collaboration, including winning a competition for a synagogue at Madison Avenue and 65th Street also in New York City.[18] Guastavino was also responsible for the construction for this building and used it as a promotion for cohesive construction on a large scale.

His career as an architect was short lived, though, and in 1886 two events pushed him further toward concentrating on construction. Guastavino was hired by a Bernard Levy, about whom little is known, to design a private residence. Levy demonstrated his confidence in Guastavino and his "radical" construction philosophies, of allowing him to use cohesive construction techniques to build his residence. The floors and roof were supported by shallow tile vaults (which Guastavino called timbrel vaults or Spanish vaults) of cohesive construction. The stairs also were constructed using only tile and cement. This building was the first to fully utilize cohesive construction techniques in the United States. The second event involved a design competition for the Arion Club in New York City; though he did not win the competition, he was awarded the contract for the construction of the floor vaults. He later claimed that the vaults were built thicker than

[17] Joy M. Kestenbaum, "Henry Fernbach," Macmillan Encyclopedia of Architects, v. 2 (New York: The Free Press,), 52.

[18] Wight, 185.

necessary or even advised, noting that he had deferred to the concerns of the architect.[19] The success of these projects, in part due to their publication,[20] established Guastavino's career as not just a contractor but that of an advisor and expert in the field of cohesive construction techniques.[21]

Through construction of his residence, Bernard Levy became a staunch supporter of Guastavino and his efforts. He encouraged Guastavino to continue refining and experimenting the technique and assisted with the applications for Guastavino's first four patents which were granted in 1885. These were patents for the construction of floor and ceiling vaults, vertical partitions and Catalan stairs; all were granted based on the novelty of his mortar.[22] Guastavino received ten more patents during the next seven years as he continued his research and application of the cohesive construction technique. The Guastavinos, father and son, eventually amassed twenty-four patents between them, with the 20th Century patents concentrating on acoustical tiles and processes in collaboration with Wallace Sabine, the Harvard University acoustical expert.[23]

As the experimental basis for many of these patents and as a means to

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[19] Collins, 192.

[20] The projects were illustrated and described in several magazines of the period including The Brickbuilder and The Decorator and Furnisher.

[21] Wight, 185.

[22] Collins, 193.

[23] Collins, 193.

build confidence for cohesive construction within the architectural profession, Guastavino organized a series of structural tests. Initial scientific tests were conducted in 1887-1889 by the Fairbanks Scale Company and established data on compression, tension and shear values to give credence to Guastavino's empirical technique. He also commissioned Professor Lanza of MIT to develop a series of tables titled "Table of Theoretical Stresses" for arches of 10% rise under uniform loading.[24] In addition, fire resistance tests were conducted in 1897, furthering his claims that the tile and cement construction was virtually unbeatable in its fire resistent quality. Capacity tests were performed both mechanically and by loading vaults constructed to certain specifications. His system's capabilities were startlingly high, especially when seen pictorially with the thin vaults loaded with pig iron.[25]

Guastavino thus was able to successfully promote cohesive construction using his early built examples, test results, transcripts of his patents, and articles in technical builders journals of the time. As a result of his concentrated efforts, Guastavino achieved a strong and well respected reputation, and began to work with prominent New York architects such as F. H. Kimball, A. H. Pickering and Buchman & Deisler.[26] He gained national recognition for his work on the 1888 Boston Public Library on Copley Square of McKim, Mead & White's design, with

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[24] Collins, 193.

[25] See Figures #4 & #5.

[26] Collins, 194.

whom he would collaborate on many more commissions as Guastavino's vaults and domes allowed McKim, Mead & White to achieve the grand spaces that became their trademark in public and institutional buildings.

In July of 1889, on the heels of such successes, Guastavino incorporated his efforts as the Guastavino Fireproof Construction Company, with main offices in New York City and Boston. He named a New Englander, William E. Blodgett, as financial officer, so that he could concentrate on the technical and marketing aspects of the company.[27] This partnership worked quite successfully with the sons of both principals eventually inheriting the firm and continuing its operation.

By the 1890s, Guastavino had developed a strong national reputation and began to work with the major architects of the time. Guastavino was also invited to speak at the prominent architecture schools, beginning with a lecture at MIT in 1889.[28] Ever eager to promote the benefits of masonry construction, in particular cohesive construction, as <u>the</u> appropriate building material with its historic roots, its strength, and its aesthetic and fireproof qualities, he lectured and wrote several books on the topic.[29]

Another successful promotional method of the Company was its advertisements. The construction lent itself to dramatic photographs and

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[27] Collins, 194.

[28] Collins, 194.

[29] A partial list of such writings by Rafael Guastavino includes: "Cohesive Construction, its Past, its Present, its Future;" <u>The Theory and History of Cohesive Construction Applied Especially to Timbrel Vault</u>; and, <u>The Function of Masonry</u>. Full bibliographic citations can be found in the Bibliography of this thesis.

Guastavino developed the advertisements around these images. These advertisements were placed in the major architectural and technical journals of the time, including Pencil Points, Brickbuilder and American Architect & Building News.[30] Guastavino also saw the value of including a history and basic technical description of cohesive construction in Sweets Catalog, a newly developed comprehensive product catalog used by architects that is still in production today. It was no accident that the best summary of the system and the Guastavino's developments can be found here with its targeted readership.

As contracts increased it became difficult to procure enough structural tiles for the commissions. Blodgett suggested that the Company build its own manufacturing plant in order to ensure that the necessary tiles would be available and to provide more flexibility in pursuing further developments of the tile.[31] Manufacturing experiments on different tile types were performed during the construction of the Biltmore, the Vanderbilt mansion in North Carolina. Soon after construction of the Biltmore was completed at the turn of the century, a production plant was opened, to manufacture the newly developed tile, by the Guastavino Company in Woburn, Massachusetts. It was here that a kiln for glazing tiles was developed and patented,[32] allowing for the increase and improvements in the type and variety of kilned structural and decorative tile

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[30] See Figure #7.

[31] Collins, 193.

[32] U.S. Patent, No. 670,777, March 26, 1901.

available. These developments also coincided with the time period, late 19th/early 20th centuries, when Guastavino, Jr. began to take over the majority of the construction management and supervision of the Company and its projects.

After his father's death in 1908, Guastavino, Jr. continued to further explore his own interests in ornamental and colored tiles that could be left exposed. He was greatly influenced by his study of both Spanish and Mexican baroque architectural ornamentation. His major innovation, though, was the introduction of acoustic tiles and plasters. Collaborating with Wallace C. Sabine, the Harvard University acoustical expert, Guastavino, Jr. received six patents for acoustical construction techniques. As part of these inventions, they developed two acoustical tiles, Rumford tile (1914) and Akoustolith (1916).[33]

The composition of the Rumford tile had small peat particles added to the terra cotta mixture. These peat particles burned during the firing process, leaving small air chambers that acted as sound absorbers. An early project that utilized this tile was St. Thomas Church (1914) built in New York City and designed by Cram, Goodhue & Ferguson. Akoustolith tile incorporated microscopic particles of pumice, which is inherently a porous material, into the tile's composition. Tests showed this tile to be 60% effective in absorbing sounds within the three octaves above middle C. Later works such as the nave of the Cathedral of St. John the Divine in New York City incorporated this tile into the design.[34] Both

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[33] Collins, 195.

[34] Collins, 195.

the Rumford tile and Akoustolith tile were meant to be left exposed, so as not to affect their acoustical properties, becoming part of the ornamentation.

Though the Guastavino Fireproof Company continued in existence through the 1950s, Guastavino, Jr. had sold his interest in the Company to Malcolm Blodgett, William's son, in 1943. The Company had managed to survive the Great Depression, but it could not survive the changing economy and aesthetics, nor the advent of new technologies. After Blodgett's death in 1956, trustees of his estates began to dissolve the Company in 1962.[35] In order to fully appreciate the significance of the Guastavinos' contributions to the reintroduction and development of cohesive construction, it is important to understand the particulars of the system, which are discussed in Chapter Two.

[35] Collins, 200.

CHAPTER TWO

COHESIVE CONSTRUCTION TECHNOLOGY

Rafael Guastavino spent a great deal of time researching masonry, both the history of the material and the construction techniques. He firmly believed that masonry construction was superior to any others being used at the time because of its physical properties of durability and fire resistance, its structural capabilities and its ease of handling.[36] He undertook a campaign to convince the general public and the profession of this superiority through several books, lectures and his projects. His promotion of the cohesive construction technique stressed that it was not a new system but rather one based in a long successful tradition. In order to explain his theories, Guastavino contrasted cohesive construction with more commonly used systems. He argued that all construction techniques could be separated into two classes: Mechanical or Gravity and Cohesive or Assimilation.

Mechanical systems included any system that relied on the "resistance of any solid to the action of gravity when opposed by another solid" for its structural

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[36] Rafael Guastavino, "Cohesive Construction. Its Past, Its Present, Its Future," The American Architect and Building News, XLI (August 26,1893)922:125.

integrity.[37] System equilibrium is achieved without taking into account the cohesive characteristics of the individual materials. As a result, the system could theoretically be dismantled piece by piece without damage and then the pieces reused in another building. When choosing the material for this type of structure, the only major consideration is that of the physical quality of hardness, i.e., in essence, whether or not the material is able to support itself without crushing.

The cohesive system is less straightforward in its methodology than the gravity system. It relies on the transformation of materials into a conglomerate through their cohesive qualities, whereupon the system is in equilibrium resisting pressure in all directions.[38] Unlike the gravity system, the cohesive system cannot be dismantled without damaging the parts beyond reusable condition.[39] With this system, not only are the physical qualities of the materials important to take into consideration but the chemical properties are equally important. Cohesion between the two materials requires a compatibility of materials in order to occur and not cause physical damage.

Guastavino proposed a historical survey,[40] abstracted here, to show the links between the two different building traditions and give clues to the usage of cohesive construction in Spain. As he saw it, the gravity system was used for such

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[37] Rafael Guastavino, Jr., Speech, c. 1914, Guastavino Archives (uncat.), Avery Library, Columbia University, New York, 2.

[38] Guastavino, "Cohesive Construction," 125.

[39] Guastavino, Jr., Speech, 2.

[40] Guastavino, "Cohesive Construction," 125-129.

monuments as the Pyramids of Egypt and the Temples of Ancient Greece, both massive building types made out of large blocks of stone utilizing bearing or post and beam techniques. The cohesive system, on the other hand, was ideal for the early concrete vaults of such ancient cultures as Assyrian, Roman and Byzantine, the latter two which occupied the modern boundaries of Spain for extensive periods of time. The range of cohesive construction also depended on the materials and skills available. The Assyrians' contribution was the initial development of firing the brick used and the attention given to the shape of the brick in order to enhance the cohesive strength.[41] The hydraulic mortar used by the Babylonians and Roman concrete were critical elements in the success of the system. Guastavino maintained that the continuity of cohesive construction was broken with the loss of such early concrete building traditions, as well as with the loss of formulas for the actual manufacture of the system's materials at the fall of the Roman Empire.[42]

Guastavino believed that there was a resurgence during the Middle Ages, which introduced a type of conglomerate construction in which a cohesive plaster was applied over stone walls, but this did not flourish as had the previous movements. The next major revival of the technique came in the late 18th century, with renewed experiments toward developing a practical concrete for construction. Earlier attempts to replicate the ancient technique had failed in the

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[41] Guastavino, Jr., Speech, 5.

[42] Guastavino, Jr., Speech, 3.

type of binder or mortar chosen or developed. The binder of a cohesive construction system is a critical element requiring a quick durable set without needing prolonged exposure to air. Further concrete developments included a modern Roman cement which was invented and patented in 1794 by James Parker. This material was manufactured using newly rediscovered natural cement but was expensive and slow setting. In 1824, another Englishman, Joseph Aspdin, received a patent for his formula for a Portland cement-based stucco that was to lead the way for a renewal in cohesive construction.[43] Guastavino was to continue these experiments to perfect Portland cement-based mortars to replace those of gypsum and lime in his constructions.[44]

The actual construction of a cohesive system differed from that of a gravity system. The gravity system relied on a substructure to support the large blocks of material during construction until the final piece had been placed. With the cohesive system a light frame guide was used to assist in the placement of the first course of tiles. When the mortar had set, the construction could continue as a self supporting system. The tiles used were laid flat in layers of distinct patterns, herringbone for vaults and concentric circles for domes, adding to the strength and durability of the system. Vaults constructed by this method were called "bovedas tabicadas," "flat arches," or "timbrel arches and vaults," which was the

[43] Guastavino, Jr., Speech, 11.

[44] Collins, 191.

terminology favored by the Guastavinos.[45]

The timbrel arch, using only ceramic tiles and a mortar to create long span vaults and domes, is conceptually more similar to a concrete membrane than the gravity system. Guastavino chose the use of tile rather than concrete based on his early experiments, as explained in his essay on The Theory and History of Cohesive Construction:

> The first attempts made in my enthusiasm for the Cohesive System were carried out in simple concrete. But I soon found that no arch work could be done with concrete -- that is, cement combined with broken stone, gravel or sand, to satisfy the needs of the epoch -- so well as it could be accomplished with tiles. By this I mean tiles laid in cement, if the material and process are well adjusted.[46]

The mortar accounts for 50% or more of the vault and the tiles essentially act as large aggregate creating an continuous shell.[47] Due to its large proportion within the completed system, the type and quality of the mortar was critical. The initial courses were placed with a plaster of paris-based mortar, in order to achieve a quick set so construction could continue without a lengthy wait. The remaining construction utilized a high quality Portland cement mortar taking advantage of its durability and strength. The Guastavino Fireproof Company was very careful about requiring a consistent quality of mortar and had composition and strength

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[45] Collins, 176.

[46] Guastavino, 14.

[47] Theodore Prudon, "Guastavino Tile Construction," Progressive Architecture, September 1989, 127.

tests conducted on most projects.[48]

The structural tiles were typically 6 by 10 inches or 8 by 12 inches and 3/4 - 1 inch thick. They were molded in units of six tiles which were scored for ease of separation after firing.[49] These were flat fired and could be either glazed or unglazed depending on the project. Unglazed surfaces were rough, to provide additional surface for better adhesion. Guastavino constantly stressed that an advantage to the timbrel vault was that the structure, fireproofing and ornamentation could be simultaneously achieved.

The actual construction process was perfected by the Guastavino Fireproof Company and protected by patents from other companies copying the technique.[50] The process was relatively simple in theory but created large vaulted and domed spaces that in the United States had only been achieved previously with lath and plaster. Whether constructing a dome or vault, the initial course of tile was set in the correct position along a wooden guide with plaster of paris. When this layer had set, succeeding layers of tile were placed with a portland cement mortar using the prior courses as a formwork. To give added strength to the vaults and to protect the mortar, the joints of the previous layer were overlapped at a 45 degree angle, creating the system's distinctive

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[48] See Appendix D for the results of two composition test conducted from mortar samples dated 1925.

[49] Prudon, 127.

[50] See Appendices A, Patents Received by the Guastavino Fireproof Construction Company and C, Information regarding a United States Circuit Court ruling for the proprietary nature of the Guastavino construction system.

herringbone pattern. In designs that called for ribbed vaults, the ribs were sometimes formed from stone or, in later constructions, tiles reinforced with metal rods. To create domes, the tiles were laid in concentric circles with the previous course supporting the next course.[51]

The number of layers required by the system varied with the span of the vault or dome, but rarely exceeded six courses at the springpoint and three at the crown. Guastavino had a great intuitive sense of the relationships between the materials and their structural capacities, but in order to provide the technical data sought by the profession a series of loading tests were necessary. In 1901, tests were conducted in a lot at the northeast corner of 108th Street and Broadway for the New York City Board of Buildings. Three arches 3 feet wide were constructed: a 2 course arch spanning 6 feet, a 3 course arch spanning 12 feet and a 4 course spanning 10 feet. The rise of each arch was 10% of its span. They were constructed with all tile joints being covered in the traditional fashion. The mortar used had a portland cement based composition. The arches were uniformly loaded with sacks of pig iron placed on a concrete fill bounded by I beams running between the spandrel of the arches.[52] The results for working loads were as follows: for the two course arch, 250 pounds per square foot, the three course arch, 312 pounds per square foot and the four course arch, 370

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[51] See Figures #8 & &9.

[52] See Figures #5 & #6.

pounds per square foot.[53]

These values are extraordinary when compared to the uniform load capacity required by standard building codes. Most of the buildings constructed with the Guastavino technique would be placed in the assembly, gymnasium, library or manufacturing categories. As a comparison, the minimum uniformly distributed live loads (pounds per square foot) required according to the 1984 BOCA Code[54] are as follows:

Assembly areas:	fixed seats	50
	movable seats	100
	stage areas	150
Gymnasiums:		100
Libraries:	stacks	150
	reading room	60
Manufacturing	light	100
	heavy	150

Another way to evaluate the system is to relate its capacity and construction detailing to a comparable but more familiar system. Guastavino put forth this comparison:

> We may consider, as a safe relation between the brick and "Timbrel Arches," a brick arch four feet six inches in span, ten per cent in rise, and four inches thick, with cement mortar as is usual in

[53] Unsigned letter to the Hon. James G. Wallace, President of the Board of Buildings, June 5, 1901, Guastavino Archives, Avery Library, Columbia University, New York.

[54] Information from Table 906 of The BOCA Basic National Building Code, 9th ed. (Danville, Illinois: The Interstate Printers and Publishers, Inc., 1984), 157-158.

> buildings, as equivalent to a ten or twelve foot span in a "Timbrel Arch," three inches thick, and with an eight to ten per cent rise.[55]

The Guastavino Company's advertisements also presented a graphic comparison with other systems, such as steel, for the construction of domes showing the simplicity and economy of the Guastavino technique.[56]

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[55] Rafael Guastavino, The Theory and History of Cohesive Construction, Applied Especially to the Timbrel Vault (Boston: Tichnor and Company, 1893), 56.

[56] See Figure #10.

CHAPTER THREE

CONSERVATION ISSUES

One of the true tests of any construction method is the test of time, where the system's performance is recorded and evaluated. The timbrel vaults and domes erected using Guastavino's cohesive construction techniques have proven themselves over the last century in the United States. The simplicity and repetitiveness inherent in the assembly not only gave it added structural capacity but also provided durability against the effects of deterioration. As a result, conservation issues are not typically concerned with a failure in the dome or vault itself but rather with the interaction of these with the main construction of the building. These issues can be divided into two broad categories, displacement and moisture infiltration.[57]

While displacement can have the most direct effect on the structural performance of the vault or dome, is the not the more commonly seen problem. This displacement is most likely to occur due to differential settling of the supporting piers, columns or walls, causing a misalignment of the tiles in the vault or dome. This misalignment will put internal stresses into the system, which can be compensated for to a certain degree but which, depending on the severity of

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[57] Prudon, 128.

the stress, will manifest themselves in the form of cracks running vertically from the spring point. These need to be observed over time; if the crack remains stable, it can be repointed in the manner of the surrounding construction. If the crack widens and/or lengthens, the source of the condition needs to be located and corrected or stabilized and the structural integrity of the dome or vault should be analyzed. This has occurred in several installations that will be looked at in closer detail in the case studies in Chapter Four.

Unlike gravity systems, these timbrel vaults and domes act as rigid membranes similar to concrete shells and as such are statically indeterminate.[58] Without a technical understanding of how they acted structurally, construction of the domes and vaults was guided more by tradition than by strict structural calculations. The thinness and flexibility of form of the system added complexity to the evaluation its performance. These factors contribute to the complications in determining whether or not a dome or vault has maintained its structural integrity. Fortunately, the increase in understanding concrete shell construction has provided information which can be applied to the Guastavino constructed elements during surveys of existing conditions.

The other conservation condition most typically affecting Guastavino construction, moisture infiltration, is more commonly seen, but its sources can be more difficult to trace. The telltale signs are white powdery deposits, (efflorescence), a dark staining on the tile surface or crumbling plaster adjacent to

[58] Prudon, 128.

the tiles (occurring most typically at the connection to the main structure and less frequently elsewhere, depending on the exterior construction. The most obvious cause of moisture penetration is due to flashing failure or, indeed, the lack of flashing in the original detail.

The latter could be attributed in many cases to the typical contractual agreements with Guastavino Fireproof Company. The Company was generally involved in the initial design conception and then hired as contractors to provide their product. Missing in the documentation of many projects was an indication of the nature and details of the interface, such as flashing, between the two systems as well as the party responsible for that interface.

This interface was especially important, as the first courses of tile were laid up with a plaster of paris mortar. While this type of mortar provided the advantageous quality of being quick setting, it was also inherently water soluble. If the vault or dome was properly constructed and protected from water penetration, there would not be a problem. Indeed in most cases the Guastavino construction elements were either internal, such as floor vaults, or were designed to be clad, as in the case of the great domes and roof vaults. When signs of moisture penetration occur in such instances, the source of the infiltration needs to be identified and rectified, and the vault or dome evaluated for the extent of any structural damage. If satisfied that the structure still retains its integrity, any loose tiles can be remortared back into place and the joints repointed. The efflorescence can be cleaned off using a soft brush so as not to damage the

glazing.

In order to gain an appreciation for the extent of conservation that is necessary with projects that utilized the Guastavino construction technique, it is important to conduct surveys of several buildings. Philadelphia has about thirty extant buildings that utilize Guastavino construction. Of these the author chose to look at four: the University of Pennsylvania Museum, Girard Trust Bank, St. Francis de Sales Church, and St. Patrick's Church. Each one has both dome and vault construction within the building, but vary in form as the Guastavino system was adapted to different design constraints. The building types also vary, and thus illustrate the range and adaptability of the system.

CHAPTER FOUR

CASE STUDIES

Information for these case studies was collected through primary sources, building files of the Guastavino Archives and actual site visits. Supporting documentation included building histories written by the owners, magazine and newspaper articles and interviews with the building owners or maintenance superintendents when possible.

THE GIRARD TRUST BANK

The Girard Trust Corn Exchange Bank, currently owned by Mellon Bank, is located at the northwest corner of Broad and Chestnut Streets and was constructed from 1905 to 1908. The building is believed to have been designed by Allen Evans of Furness, Evans and Company, in collaboration with the New York firm of McKim, Mead and White. The drawings, however, were done in the office of McKim, Mead and White. The style for the bank was neo-classical revival chosen to promote a sense of connection to a past great democracy, Greece. Choosing a style based on philosophical reasons, was a popular American tradition starting in the early 19th century as an attempt to promote a national aesthetic.

The bank's main floor plan includes a double height banking room with single height side galleries; the basement houses the safety deposit vaults. The two prominent street facades are patterned after Ionic temple fronts. The bank has a flat roof hidden behind a balustrade, giving added prominence to the main feature, the great marble clad dome with a glass oculus in the center. With a span of 101' it was the largest dome in the Western Hemisphere when constructed, though it has since been surpassed.[59] It is a steel frame building with white marble ashlar curtain walls both on the exterior and interior.[60] There is also an oculus opening in the main floor, behind the teller counter, providing natural daylight to the basement level.

By this time Guastavino had already collaborated with McKim, Mead & White to provide the domes and vaults that were an essential part to the success of their designs for such building as the Brooklyn Institute of Arts and Sciences (1897) and the Boston Public Library (1898). It is not surprising, then, that Guastavino was called upon to construct the Girard Trust Bank dome. The dome is actually a double shell, the inner shell of which has large rectangular coffers. The outer shell was constructed of a buff color tile laid in concentric circles. Between the shells of the dome is an attic maintenance space and access to the two oculi. The floor system of the main floor of the banking hall is also of

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[59] See Figure #11.

[60] Richard Webster, Philadelphia Preserved: Catalog of the Historic American Buildings Survey (Philadelphia: Temple University Press, 1981), 130.

Guastavino construction. Here shallow domical vaults were used to span between the steel frame skeleton.[61] Both the visible portion of the inner dome in the banking room and the basement vaults have been plastered coordinating with the white finish of the other interior materials.

The author's observations during a site visit and interview with the bank's facilities and real estate department manager revealed that no conservation work on the Guastavino construction had been necessary.[62] The tiles were in excellent shape, showing no signs of efflorescence or water staining. The plaster work was intact and had only been repainted or reworked in the basement as alterations to the floor plan had been made. There were no visble settlement cracks on the outer side of the lower dome or the inner face of the exterior dome. According to Mr. Zimmerman,[63] Mellon Bank, the current owners had not had to perform any repair work on the tiles since acquiring the building in 1983. Moreover, they had been informed by the former owners that nothing beyond a regular maintenance to the surrounding flat roof and drainage systems had been necessary in the past.

Several factors have likely contributed to this extraordinarily low level of required maintenance. First, the basement vaults are completely internal and are

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[61] See Figures #12 & #13.

[62] Site visit and interview with Craig Baclit, Mellon Bank Real Estate Management Department, February 7, 1992.

[63] Interview with Ed Zimmerman, Mellon Bank Real Estate Management Department, January 21, 1992.

thus protected from direct water penetration. Adequate flashing and drainage details in the walls must work to prevent water from infiltrating the connection between the walls and vaults. The inner dome is, of course, also internal with setbacks from the exterior walls and protected by the outer dome.

The lack of water damage to the outer dome was the most surprising, as other similar applications showed some signs of deterioration. The construction of the marble cladding over the tile must have been well executed and water drainage details well worked out. The working drawings for this project indicate that the Guastavino Company was responsible for the exterior marble cladding of the outer dome in conjunction with the actual construction of it.[64] This maintenance record is a credit to the quality and durability of the Guastavino construction process and the ability of the architects to integrate it into their design.

ST. PATRICK'S ROMAN CATHOLIC CHURCH

One of the early Catholic parishes to be established in Philadelphia was St. Patrick's. It was founded in 1839 to serve people living in the southwest quadrant of Centre City. After using a rented house for the Chapel, it was decided to

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[64] Girard Trust Building file, Guastavino Archives, Drawings and Archives, Avery Architectural and Fine Arts Library, Columbia University, New York.

construct more permanent buildings. Land was purchased in 1841 at the northwest corner of Schuylkill Third and Murray, now the corner of 20th and Rittenhouse Streets. A brick building in a modified neoclassical style was designed by Napolean LeBrun, who later designed the Cathedral of Sts. Peter and Paul, and construction was completed by the end of the year.[65] This building was stuccoed in 1860 as part of the upgrading of the Parish facilities.[66] By the turn of the Century, though, it was obvious that the parish community had grown to the point where a larger building was necessary and the decision to rebuild on the existing site was made.

The parish chose the architects LaFarge and Morris to design the new structure. LaFarge and Morris used the Byzantine style as their main design inspiration in keeping with the early roots of Christianity.[67] The incorporation of vaults and a low dome as the structural system which would also dictate the spatial qualities of the interior volumes was consistent with the Byzantine inspiration for the design. The plan, restricted by site constraints, is essentially a large rectangle without the traditional side aisles. The interior finishes, however, are quite lavish including several different marbles, tapestry brick, stained glass and glazed tiles. The exterior is an interesting combination of the Byzantine style with a Greek temple portico applied to the main facade. The building is a

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[65] William E. Campbell, ... how unsearchable his ways: One Hundred Twenty-fifth Anniversary, Parish History of St. Patrick's Parish, Philadelphia, 1965, 6.

[66] Campbell, 9.

[67] Campbell, 68.

masonry structure with exterior face brick and granite cladding. It has a simple gable roof running along the longitudinal axis, with a cross gable at the dome lantern.[68]

Guastavino's timbrel vaults were chosen to satisfy the design's requirements for vaulted long spans.[69] The main Church can be divided into four bays of equal dimensions, running parallel to the entrance facade. The first two bays, nearest the entrance, have low rise domical vaults. The third has a steeper rise and incorporates a low dome, the center of which contains a stained glass skylight. The fourth bay, over the altar, terminates the progression with a semi-circular apse. The vaults are supported on large brick piers which also act as buttresses for the side walls. The vaults are 71' above the floor at their crowns and the dome is 9' higher.[70] Both glazed and unglazed tiles are used in the Guastavino construction and the vault ribs are of brick and terra cotta. The color scheme includes light browns and neutral colors; the field pattern of the vaults is the

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[68] See Figure #14.

[69] Subcontract agreement between R. Guastavino Company and Melody & Keating Contractors dated September 16, 1910, St. Patrick's Church building file, Guastavino Archives.:

"The said R. Guastavino Co., agrees to furnish all the materials and provide all of the labor, transportation, apparatus and utensils required for the complete finishing of all the tile vault construction, which includes all the vaulted ceilings and soffits, the entire first floor construction, the floor construction under and over the choir and organ lofts, and the entire roof construction, the fireproofing of the lantern, tile steps, the pierced ornamental terra cotta lunetts and all other tile vaulting as shown on the plans including the furnishing and erection of all the steel and ironwork required for the supports, anchoring, tying or securing in place of work included in this contract..."

[70] Campbell, 69. See Figure #15.

characteristic herringbone.[71]

The lower chapel, the "Crypt Chapel", also has Guastavino tile as part of its composition. Here the timbrel vaults span smaller rectangular bays forming the floor structure and support for the church building above, and the finish ceiling of the lower chapel. Originally the tiles of these vaults were left exposed, as can be seen in early photographs.[72] According to a parishioner, John Schiavo, they were plastered over in the late 1950s.[73] The other interior finish materials are similar to the upper church, and the main altar is from the original 1841 church building.[74]

The tiles throughout the Church building show signs of extensive water infiltration, and the parish is undertaking major repairs in both the lower and upper church. In the lower church, damage to five ceiling vaults was caused by leaking radiator pipe located between the ceiling vaults and floor of the main sanctuary. Part of one side vault, along the north wall, was removed to determine the extent of the damage and to repair the radiator pipe and currently is awaiting replastering. There does not appear to be any structural damage and, as this is one of the more seriously damaged vaults, the others are probably free from lasting damage. Once the tiles dry out, the efflorescence will be brushed off and

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[71] See Figure #15.

[72] See Figure #17.

[73] Site visit and Interviews, March 24, 1992.

[74] Campbell, 6.

the area replastered to blend with the surrounding areas.

Where the tiles had been removed, the construction technique could be studied. It consisted of a vault constructed of five layers of tiles upon which tile piers were constructed that supported reinforced tiles forming the floor plane above. Steel I-beams were also located in the vault ribs creating a rigid ring to support and to tie the system together. Unfortunately, steam lines for the radiator heating systems were located in the space between the tile constructions. It was also interesting to note that the tile next to the ribs, the inherently weak joint of the system due to the use of a plaster of paris mortar, had the greatest water absorption as seen by the concentration of efflorescence, but in this case none of the tiles were loose.[75]

Signs of water damage were also apparent at the vaults of the main sanctuary, especially at the springpoints along the south wall. Heavy efflorescence and staining was visible at the first two piers with lesser amounts at the pier closest to the altar. In talking with Therese Joyce, the parish business manager, this roof over the section near the altar had already been repaired and the other bays were to be part of the next phase of maintenance projects.[76] Staining was limited to the springpoints of the vaults along the south wall and above the rib of the arches along the south wall. It was interesting to note that the same condition did not occur along the more protected north wall or at the base of the apse

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[75] Site visit, March 24, 1992.

[76] Site visit and Interview, March 24, 1992.

dome at the altar.

The author was able to gain access to part of the attic space, in an attempt to trace the water infiltration source and full extent of the damage to the tiles. The structural system utilizes a double shell construction technique, similar to that of the Girard Trust Bank, of unglazed Guastavino tiles.[77] In the accessible portion of the attic, the lower system creates the volumetric form of the Church and the upper system forms a barrel vault spanning from wall to wall which then supports the roof structure. The attic space above the side aisles, where the organ loft and choir loft are located below, paralleling the main attic, were not accessible but can be seen on the cross section.[78] Inspection from the choir loft on the south side indicated that these tiles are in fair condition, but damage in the organ loft could not be assessed due to limited access. Due to their location, it can be speculated that these tiles would be in a similar good condition to the other tiles along the north wall.

The water damage was extensive all along the south wall in the attic and a great number of tiles had fallen on the walkway. These tiles and many of the tiles overhead were damp and discolored from water infiltration. Moveover, some of the tile adjacent to the wall were saturated and a few were loose indicating that the mortar must be deteriorating or dissolving.[79] This is the inherently weak

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[77] See Figure #18.

[78] See Figure #19.

[79] Site visit, March 24, 1992.

joint where plaster of paris was typically used for the first course of tiles. A structural engineer should be contracted to do an evaluation on the system to determine its integrity. The water penetration is quite extensive with water soaking through the upper tiles and ponding on the lower tiles. As this was not an expected condition, there is no drainage provided in the attic space and the lower tiles have absorbed the standing water causing the efflorescence seen below in the Church. The large amount of water does not appear to be solely the result of a poorly designed drainage system but, rather was caused in part by the deterioration of the roofing material. When asked about the condition of the roof, John Schiavo, indicated that there had been large areas of failure and that the roofing and drainage systems were being replaced in phases.[80] Even with the source of the leakage repaired, the water saturated tiles will take a great length of time to dry out and both tile replacement and repointing will be necessary.

ST. FRANCIS DE SALES ROMAN CATHOLIC CHURCH

The late 19th Century saw a large increase in the population of West Philadelphia, with Irish Catholics as a major ethnic group. Archbishop Ryan established the new Catholic parish of St. Francis de Sales in 1890 in response to

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[80] Interview with John Schiavo, maintenance superintendent of St. Patrick's Church, March 24, 1992.

this growth. The parish included the neighborhoods now called Spruce Hill, Garden Court, Cedar Park, and Kingsessing, i.e. roughly bounded by 42nd Street, Woodland Avenue, 54th Street and Market Street. The parish was situated between St. James at 38th and Chestnut Streets and the Church of St. Clements at 71st Street and Woodland Avenue.[81]

The first masses of the new parish were held in a rented space on the second floor of a building at the corner of 49th Street and Woodland Avenue. The parish soon outgrew this space and began to look for land to erect its own buildings. Land was purchased at the northeast corner of 47th and Springfield Streets in October 1890. The first building constructed on the site was a combination school/chapel, completed in September 1891.[82] A granite and limestone structure, it was designed by Adrian Smith who was trained by Charles M. Burns, a Philadelphia ecclesiastical architect.[83] Upon Smith's death, a John Flynn completed the building. In 1893, the rectory was designed by Dennis Doyle and costructed by his father, James Doyle, in a similar style and material palette as the school/chapel.

After the death of Father O'Neill, the first pastor of St. Francis de Sales parish, Rev. Michael J. Crane was assigned to the position. He continued the

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[81] _____, Golden Jubilee of St. Francis de Sales Parish, Parish History, Philadelphia, 1940, 17.

[82] Parish History, 18.

[83] A Historical and Architectural Analysis of St. Francis de Sales Roman Catholic Church, prepared by John Milner Associates,Inc., Philadelphia, October 1988, 9.

building campaign, and it is during his tenure that the present church building was constructed. This structure was to become a landmark not only for the neighborhood but for the city as a whole. Rev. Crane showed great foresight when he described the church he imagined as:

> an edifice worthy of the dwelling place of the King of kings: one in which beauty of art would mingle with splendor and stateliness of proportion; one in which rare marbles would be wrought into an illustration of some religious truth; one in which the soul would be lifted up to exaltation; an edifice in mystical beauty; a church rich with storied windows, enduring for ages, a perpetual witness to the faith of his people.[84]

Henry Dagit, a Philadelphia architect, was hired to design the Church building. Dagit's career had been shaped by his ten year stint as as architect to the Archdiocese of Trenton, New Jersey, and his legacy includes a considerable number of religious buildings both in the Trenton and Philadelphia areas.[85] Dagit chose to design the Church in a Byzantine-Romanesque style, uncommon for Catholic religious buildings, which tended to be of the Gothic style.[86]

The promotion of the Byzantine-Romanesque style had started as a counter movement in the mid-19th Century in France as the result of a competition for a new church to be built for Sacre Coeur in Montmartre in Paris. The winning design by Paul Abadie reflected the influence of his studies and restoration of several 12th Century Byzantine-Romanesque churches in France.

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[84] Parish History, 24.

[85] Sandra L. Tatman and Roger Moss, Biographical Dictionary of Philadelphia Architects: 1700-1930 (Boston: G. K. Hall and Company, 1985), 181.

[86] See Figure #20.

The church of Sacre Coeur with its white marble, domes and vaults was to become an alternate basis for the design of religious buildings. The Mediterranean roots of Byzantine architecture corresponded to the area of origin of the Jewish and Christian faiths, creating a strong argument for the use of this style. The design of the St. Francis de Sales Church embodies all these stylistic components, mixed with a rich palette of colored mosaics.[87]

This design concept was ideal for the collaboration of Henry Dagit and the Guastavino Fireproof Construction Company. While Dagit was in charge of the overall design, the Guastavino Company was also retained by Rev. Crane for

> "all Dome work, Nave vault work, choir gallery and Sanctuary vaults and Four Tower domes together with all the necessary steel work as may be required by the Department of Building Inspection of Philadelphia and in accordance with the Architect's directions, who will supervise the work..." [88]

This early decision to use the Guastavino construction techniques allowed for extensive collaboration during the design development process both for forms and ornamentation.[89] The specifications also provide a clue to the closeness and uniqueness of this partnership. Guastavino construction is specified for all domes and vaults by name with only passing comments on materials and patterns and no

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[87] Milner Associates, Inc., 5-6.

[88] Contract between the Catholic Diocese of Philadelphia and the Guastavino Company, May 8, 1908, St. Francis de Sales File, Guastavino Archives, Avery Library, Columbia University, New York.

[89] See Figure #21.

technical information.[90]

Construction for the Church began in 1907 with the laying of the cornerstone and was completed in 1911. The building is constructed of reinforced concrete and brick with an exterior veneer of white marble ashlar. The carved details are of limestone and polished columns flank the entry doors. Marble, tile, terra cotta, brick and stained glass are used extensively in the interior for both cladding materials and the symbolic ornamentation. The plan is a modified basilican plan without side galleries and with abbreviated transepts. The dominating feature of the Sanctuary is its great volume created through the simple forms of barrel vaults and a large dome at the crossing.[91]

There are five domes on the Church building, the main one at the crossing and four smaller tower domes at the corners. The tower domes rise 97' in height and are each topped with small terra cotta cross. The main dome springs from 90' above the floor to a height of 126' at the top of the cross on the dome's lantern. This dome is 62' in diameter and utilizes both glazed and unglazed Guastavino tiles.[92] The majority of the tiles are laid in the characteristic herringbone pattern. The dome is supported on concealed steel beams which rest on four large arches following the profile of the barrel vault. These arches are supported on reinforced concrete piers, clad in marble, at the crossing points.

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[90] Specifications for St. Francis de Sales, St. Francis de Sales File, Guastavino Archives, Avery Library, Columbia University, New York.

[91] See Figure #22.

[92] Parish History, 33.

From the exterior the dome appears to be resting on a brick drum.[93]

Another prominent feature of the Church is the barrel vaults. The main one running along the longitudinal axis is divided into four sections including a lower section over the altar.[94] Divisions occur at either side of the transept dome, and at large proscenium arches over the choir loft in the rear of the Church and the altar. The short transcept axis is also barrel vaulted. Guastavino tile is used for these vaults, arranged in the characteristic herringbone pattern. The color palette ranges from a cream to buff and light brown.[95]

Original drawings, noted to include Guastavino tile exposed on the main dome, show gabled roofs of tile over the barrel vaults.[96] Currently these vaults are covered with a batten seam copper roof. All the domes were retiled in 1955 using a process where gunite was sprayed over the Guastavino tiles and new ceramic tiles set over it in a similar design to the original. These repairs were necessitated by the major deterioration mechanism for Guastavino construction, water infiltration. Tiles above the integral gutter system had been damaged through thermally induced expansion and contraction, of the dome and were further weakened as ponding occurred in the gutters. The combination of these allow some water penetration to the interior, which exhibited itself as

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[93] See Figure #23.

[94] See Figure #24.

[95] Site visit, March 7, 1992.

[96] See Figure #25.

efflorescence but more seriously caused delamination of the harder outer layer of tiles, exposing the more porous inner layers.[97]

Efflorescence is, also, visible on the interior brick and tile faces that align with changes in the roof heights. This is especially noticeable in the proscenium arch above the altar area. Recent roof repairs have patched a major roof leak on the northeast side. Modern ceramic tiles placed over the original tiles on the transept end wall are delaminating and efflorescence is visible toward the top of the arch where there is a change in roof height. Here, too, it appears to be a weak connection between the wall, Guastavino structure and roof systems that is allowing water infiltration.[98]

An unsigned drawing, by a member of the Church staff in the Guastavino archives received by the Company in 1931 indicates cracking in two sections of the longitudinal vault.[99] The cracks are in the sections nearest to the dome and are perpendicular to the axis of the vault. There is no record of what repairs were done at the time but three cracks on the rear portion, though repointed is still visible. These cracks were not just confined to the mortar joints but cut through tiles. This seems to suggest that there was differential settling between the dome bay and the bordering ones.

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[97] Milner Associates, Inc., 17.

[98] Site visit, March 7, 1992.

[99] St. Francis de Sales File, Guastavino Archives, Avery Library, Columbia Library, New York.

In the 1886, the City of Philadelphia gave the University of Pennsylvania twelve acres of land south of Spruce Street between 33rd Street and the Schuylkill River to construct a museum to house the collections of the Department of Archeology. Rather than awarding the design contract through a competition, the Building Committee gave the commission to a group of four architects, Wilson Eyre, Walter Cope, John Stewardson and Frank Miles Day, all of whom were professors at the University's School of Architecture.[100] The architects collaborated under the direction of Wilson Eyre on a grandiose scheme in the tradition of 19th Century eclectism, in which several historic styles were combined into an original composition.[101] The plan was laid out to be symmetrical around a large central rotunda flanked by gallery wings and smaller rotundas. The first construction campaign was from 1893-1899 when the U-shaped brick building, on the southeast corner of 33rd and Spruce Streets, was built.[102] This section was constructed using traditional construction methods and upon completion the University Museum, originally known as Museum of Science and Art, officially opened its doors.

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[100] _____, "The New Museum Building," Bulletin of the Free Museum of Science & Art of the University of Pennsylvania, II (December 1912)2:69.

[101] John Gallery, ed., Philadelphia Architecture: A Guide to the City (Cambridge, MA: The MIT Press, 1984), 80.

[102] See Figure #26.

By 1910 the Museum collection had outgrown its space and the need for an auditorium became apparent. The original architects were retained and plans were made to construct one of the smaller rotunda spaces, following the original site plan. The space was to have an auditorium on the ground floor and an exhibit space above. As the design progressed, however, it soon became obvious that traditional construction techniques would not be suitable. It was originally thought that the roof dome would be supported on columns within the space, something that was not advisable in an auditorium or exhibit space.[103]

The Guastavino construction technique provided the solution of a hemispherical dome which would span the 90' room supported on piers projecting from the outer circular walls of the space. Cohesive construction was used for both this roof dome and a dome creating the ceiling for the auditorium.[104] The auditorium dome has a shallower curvature and is an early built example utilizing the acoustical tile, later known as Rumford tile.[105] This tile was also used for the walls and at the proscenium arch to provide acoustical control.

As this space too was outgrown, the wing, currently the Egyptian wing, that would connect the rotunda to the central one was constructed in 1922.[106] This

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[103] _____, "The Building," <u>The Museum Journal</u>, VI (December 1915)4:151-152.

[104] The Museum Journal, December 1915, 152.

[105] See Figures #27, #28 & #29.

[106] _____, "Building Operations," <u>The Museum Journal</u>, XV (December 1924)4:256. See Figure 30.

building design is based on a basilica plan. The high central space is used for exhibits flanked by the lower side aisles that house support activities. A Guastavino timbrel barrel vault was used to span the main space with separate vaults spanning the side aisles, giving the exterior its traditional composition of bi-level roofs. The floor of this space and the ceiling of the lower Egyptian wing is also of Guastavino construction. Here the ceiling is created using smaller domical vaults giving the appearance of a cryptlike space.[107] In both buildings, the wing and the rotunda, the Guastavino construction directly supports the tile roof without the addition of supporting trusses or steel members.

The author interviewed the building superintendent, Don Fitzgerald, about the condition of the Guastavino tiles and any maintenance that had been required.[108] According to Mr. Fitzgerald, the only required repairs were due to a deteriorated internal downspout that was allowing water to penetrate the tiles. At the time, the downspout was replaced and a water detector was added as a safety measure. There was no structural damage to the tiles, but there is some staining and efflorescence evident on the tiles of the rotunda, the area affected directly by the leaking downspout.

A building tour confirmed the good condition of the Guastavino

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[107] See Figure #31.

[108] Interview with Donald Fitzgerald, Building Superintendent, University Museum, University of Pennsylvania, Philadelphia, March 31, 1992.

construction.[109] The tile pattern of main vault in the Upper Egyptian wing differed from other viewed as it was a stack bond pattern rather than the more typical herringbone. As noted in other examples, there was some staining and efflorescence along the springline, the weak place in the system, on both sides. This can be attributed to the flashing detailing since it corresponds to the different roof planes. A curious regular staining pattern of four rows of dark blotches covering about 3 to 4 square feet each was visible in the field of the vault. There does not appear to be an easy explanation for this, but one possibilty is that the stains correspond to tile posts above the vault which support the roof.

Guastavino construction was also used for the floor/ceiling and roof structure in the rotunda portion of the building. The author was able to gain access to the space between the ceiling vault of the Harrison Auditorium on the ground floor and the floor of the Chinese Rotunda above. There is no sign of deterioration or water infilitration. The structural system is quite interesting as, here too, no steel is used. Three thickened tile rings, acting as tension rings, support posts also constructed of Guastavino tiles. Concentric vaults span from post to post and support the floor structure of the gallery above.

The dome of the Chinese Rotunda showed the most signs of deterioration. The tiles above the clerestory windows were darkened due to water infiltration attributed to the leaking downspout. There was also efflorescence along the

[109] Site visit to the University Museum and interview with Don Fitzgerald, Building Superintendent, University Museum, University of Pennsylvania, Philadelphia, April 14, 1992.

transition line between the brick arches over the clerestory windows and the adjacent tiles. About 1/3 of the dome appeared to have been repointed at some time with a white mortar different from the buff colored original mortar. There were definite segments forming lines toward the top of the dome that had been repointed. These areas corresponded with location of long vertical cracks in the brick wall of the rotunda space. As these cracks were not confined to the mortar joints and continued through the bricks in many cases and having been told of the existence of underground streams, it would appear they could be attributed to differential building settlement. Though the cracks are small in width, they bear monitoring periodically for movement.

CONCLUSION:

In all buildings chosen for case studies the Guastavino tiles are still intact and performing their structural function. Where problems occurred, the cause could be traced to a source outside of the Guastavino construction rather than to a system failure. The main conservation issues are related to water infiltration occurring at the interface between buildings elements and construction detailing, or due to the introduction of a water source as in the radiator pipes at St. Patrick's Church and the internal downspouts at the University Museum. The

resulting signs are manifested at the points of least resistence in the Guastavino system -- typically at the springpoints of the domes and vaults where water can pond and at the joints of the initial layers are water-soluble plaster of paris.

While this survey was limited to four buildings in the Philadelphia area, the consistency of conditions creates a basis for evaluating examples of Guastavino construction. It would be interesting, though, to determine if climatic differences affected the performance of the tile construction. As water infiltration is a major cause of potential deterioration, areas with greater rainfall might create more accelerated conservation issues. Another category for comparison is the effects of the manufacture of the tiles themselves; how each type performs in comparable locations and how the composition determines where the different tiles are specifically used.

CONCLUSION

The success of the cohesive construction systems developed by Guastavino Fireproof Construction Company can be measured in several ways, from their technological developments to the durability of the system to aesthetics. Cohesive construction has had a history of working with materials, exploiting them to their full structural potential. After a careful study of this tradition, the Guastavinos' began their experiments with different types of mortar and tiles to create a modern cohesive construction system. Out of these experiments came twenty-four patents relating to different construction techniques and compositions of tiles such as the acoustic tiles, Rumford and Akoustolith. The overall systems developed proved to be quite durable as can be seen in the previous case studies. Damage, when evident, does not typically create a structurally unsound condition due to the system's built-in cohesiveness.

The widespread use of Guastavino construction can be credited to its compatibility with the stylistic trends and its comprehensiveness.[110] The system not only served as the structure for the building but could also provide the ornamentation. This combination proved to be a winning one, as illustrated by the fact that the Company has work in forty-one states, five Canadian provinces

[110] See Figure #32.

and nine additional countries including India. Another interesting statistic is from a poll in 1900 to determine the ten most beautiful buildings in the United States. For buildings constructed after Guastavino's arrival in this country, Guastavino worked on all but two.[111]

The Guastavino Construction technique is not used on a wide scale in the United States. It has been surpassed by a modern construction technique, thin shell concrete, which can replicate the forms but not necessarily the decorative aspects. One drawback of the system from the start is that while the materials were relatively inexpensive and competitively priced, it was quite labor intensive. Today's economics have precluded labor intensive procedures due to the cost. An interesting comparison would be to determine the actual square foot costs of the Guastavino system and a comparable construction technique. In order to do an accurate comparison, it must be noted that the Guastavino system combines the structural system, fireproofing, acoustical controls and ornamentation in one process unlike current construction techniques.

Probably the more decisive reason, though, for the decline in the system's usage is the proprietary nature of the system. The formulas for the composition of the mortar and tiles were held by the Company and not public domain information. Also, while the Company used its own construction crews training them in the technique, the protection afforded by patents and litigation prevented

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[111] George Collins, "The Transfer of Thin Masonry Vaulting from Spain to America," Journal of the Society of Architectural Historians 27 (October 1968)3:199.

any comparable company from forming.[112] As a result the technique seems to be a lost art. Future studies might work toward recreating the actual process through a study of patents and material analysis of existing examples.

[112] See Appendices A, Patents Received by the Guastavino Fireproof Construction Company, and C, Information regarding a United States Circuit Court ruling for the proprietary nature of the Guastavino construction system.

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APPENDIX A

PATENTS RECEIVED BY THE GUASTAVINO FIREPROOF CONSTRUCTION COMPANY

Patent # 323,930	Construction of Fireproof Buildings, August 11, 1885
Patent # 336,047	Fireproof Building, February 9, 1886
Patent # 336,048	Construction of Fireproof Buildings, February 9, 1886
Patent # 383,050	Fireproof Building, May 15, 1888
Patent # 430,122	Construction of Tiled Arches for Ceilings, Stair-Cases, etc., June 17, 1890
Patent # 464,562	Construction of Buildings, December 8, 1891
Patent # 464,563	Cohesive Ceiling-Floor, December 8, 1891
Patent # 466,536	Cohesive Ceiling-Floor, January 5, 1892
Patent # 468,296	Construction of Buildings, February 2, 1892
Patent # 468,871	Construction of Fire-Proof Buildings, February 16, 1892
Patent # 471,173	Hollow Cohesive Arch, March 22, 1892
Patent # 481,755	Cohesive Combined Lintel-Ceiling, August 30, 1892
Patent # 548,160	Building-Tile, October 15, 1895
Patent # 670,777	Kiln for Glazing Tiles, March 26, 1901
Patent # 915,026	Structure of Masonry and Steel, March 9, 1909
Patent # 947,177	Masonry Structure, January 18, 1910
Patent #1,052,142	Masonry Structure, February 4, 1913
Patent #1,057,729	Masonry Structure, April 1, 1913
Patent #1,119,543	Wall and Ceiling of Auditoriums and the Like, December 1, 1914
Patent #1,197,956	Sound-Absorbing Material for Walls and Ceilings, Spetember 12, 1916
Patent #1,440,073	Acoustical Facing Material for Interiors, December 26, 1922
Patent #1,563,846	Sound-Absorbing Plaster and Method of applying same, December 1, 1925
Patent #1,917,112	Acoustical Product, July 4, 1933
Patent #2,143,980	Suspended Ceiling Structure, January 17, 1939

APPENDIX B

PARTIAL LIST OF BUILDINGS IN PHILADELPHIA UTILIZING GUASTAVINO CONSTRUCTION TECHNIQUES[113]

New M. E. Church (St. Andrews Methodist) - 1907
Girard Trust Company Building - 1908
House and Stables, Miss Julia Garrett - 1908
Residence, Charlton Yarnall - 1908
Gymnasium, Starr Garden Recreation Park - 1911
Baptistry, Our Mother of Sorrows - 1911
St. Francis de Sales Church - 1911
St. Patrick's Church - 1911
St. Columba's Church - 1912/1913
Chestnut Street Opera House (demolished) - 1913/1914
Philadelphia Electric Company Power Station #A2 - 1914/1915
Bell Telegraph Building - 1915
Rotunda, University Museum, University of Pennsylvania - 1915
Overlook Pavilion, League Island Park (FDR Park) - 1919
Jefferson Hospital Annex - 1923/1924
University Museum Addition, University of Pennsylvania - 1924
Federal Reserve Bank - 1926
Hahneman Medical College and Hospital - 1927/1928
Atwater Kent Manufacturing Company Building - 1929
Phila. Electric Company Office Building (Edison Bldg) - 1929
Philadelphia Customs House - 1930
Presbyterian Hospital - 1930
Girard College Chapel - 1932
Ben Franklin Memorial Hall, Franklin Institute - 1933
Naval Aircraft Factory - 1937
Cathedral Church of Christ - 1938
Naval Aircraft Factory Building #533 - 1938
Municipal Court Building - 1939
St. Martin of Tours - 1954
E. W. Clark Building -

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[113] This list was compiled by the author from the Philadelphia Files of the Guastavino Archives (uncat.), Avery Architectural and Fine Arts Library, Columbia University, New York. It may not be a complete list.

APPENDIX C

LITIGATION ON GUASTAVINO CONSTRUCTION C.1917

BOSTON OFFICE
OLD SOUTH BUILDING.

FACTORY.
WOBURN, MASS.
TELEPHONES AT OFFICES AND FACTORY.

NEW YORK OFFICE.
FULLER BUILDING.
23D STREET, B'WAY & 5TH AVE.

R. GUASTAVINO CO.,

COHESIVE TILE CONSTRUCTION.

[redacted]

R. GUASTAVINO, PRESIDENT
WM. E. BLODGETT, TREASURER
A. E. ROBERT, SECRETARY

NEW YORK.

To Whom It May Concern:-

Several cases have recently been brought to our attention by builders and architects where bids other than our own have been submitted upon plans and specifications calling for the construction of "Guastavino Arches" (also known as "Timbrel Vault", "Spanish Tile", "Cohesive Tile" arches). In one case the party went so far as to use photographs of work done by us. In another instance an arch built by one of these parties being improperly designed and constructed, fell, causing thousands of dollars damage to the structure. These people shortly thereafter went out of business, and we were called in by the architect to rebuild the work properly, which we did.

In order to protect the trade generally against imposition from parties who represent themselves as prepared to undertake this kind of construction in the same manner as the undersigned, and also to protect ourselves against unfair methods of competition, we have found it necessary to resort to the courts. In a recent suit brought by us in the United States Circuit Court for the Southern District of New York against John Comerma and The Comerma Company, U.S. Judge Hand granted to us two injunctions, one of which enjoined the defendants:

> "From in any way using the names 'Guastavino arch,' or 'Timbrel arch,' or 'Timbrel vault,' or any other names similar to those and calculated to deceive the public, to designate the form of building construction built or constructed by the defendents, or from making bids for or soliciting contracts to build the Guastavino arch, the Timbrel arch, or Timbrel vault, and from in any way using photographs, pictures, or other reproductions of any work actually done by complainant to advertise the work of said defendants."

APPENDIX C (cont'd)

R. GUASTAVINO CO.

FULLER BUILDING

NEW YORK

The other injunction restrained the defendants:

> " From using the phrases 'Spanish tile' or 'Cohesive tile' to designate the form of building construction built by the defendants, or either of them, unless such defendants, and each of them, add as a suffix whenever they, or either of them, use said names, the following phrase, in letters as conspicuous as the names themselvs: 'Not made by Guastavino, the original maker of such arches.'"

Looking back over a business career of over a quarter of a century, we take pardonable pride in the reflection that the form of tile arch construction introduced into this country by our Mr. Rafael Guastavino, Sr., in 1881, has been so well received by architects and builders generally that it has become recognized as the standard of its type, and that few buildings of importance in this country, erected within the last fifteen or twenty years, do not contain some specimen of our work. We have endeavored, and shall always endeavor to make our bids and prices as low as the quality of the work done by us will permit. It should be remembered that long before the plans calling for our work get into the builder's hands, we have spent much time and money in drawing and planning the work to suit the architect's requirements for the building, and we therefore object to the practices of those who, not willing to stand on their own merits, endeavor to climb into prominence upon ours, and we feel certain that architects and the trade generally will support us in our determination to eliminate such methods from the trade.

Yours respectfully,

R. GUASTAVINO CO.

APPENDIX D

The following are the results of mortar analysis tests conducted by the firm of Skinner, Sherman & Esselen, Inc. Chemists and Engineers. 276 Stuart Street. Boston, MA. The original documents are in the Guastavino Archives in Avery Architectural and Fine Arts Library at Columbia University, New York.

SAMPLE ONE:

Case No. 6397
September 14, 1925

Received sample of plaster said to contain pumice, lime and white cement on September 11, 1925

Analytical Results:

Moisture	2.4 %
Insoluble in Acid	43.4
Loss on ignition	12.0
Soluble silica	2.73
Soluble iron & Aluminum Oxide	1.03
Calcium Oxide	29.82

Comments:

Figuring from the above results on the basis that the ingredients are pumice, lime and white Portland cement as given by Mr. Blodgett, the composition of this material figures approximately 45% pumice, 15% white Portland cement and 40% of a hydrate lime, high in magnesia.

APPENDIX D (cont'd)

SAMPLE TWO:

Case No. 6999
January 7, 1926

Received plaster sample December 31, 1925

56% Aggregate		**44% Binder**	
Silica	62.9%	Loss on ignition	11.8%
Iron Oxide & Alumina	15.1	Insoluble	1.2
Calcium Oxide	2.4	Iron Oxide & Alumina	6.1
Magnesia	0.9	Calcim Oxide	34.3
Undetermined		Carbon Dioxide	trace
(prob. alkali)	18.7	Sulfuric Anhydride	46.5
		Magnesia	trace
	----		-----
	100.0%		99.9%

From a study of these results, we are of the opinion that this plaster was made by mixing approximately equal parts of aggregate and binder. The analysis of the aggregate corresponds with the composition of a feldspar while that of the binder indicates a plaster of paris.

ILLUSTRATIONS

Figure #1: Residence (1866), Barcelona, Spain, designed by Rafael Guastavino [Peter B. Wight, "The Works of Rafael Guastavino. Part I. As Architect," The Brickbuilder 10 (April 1901)4:79.]

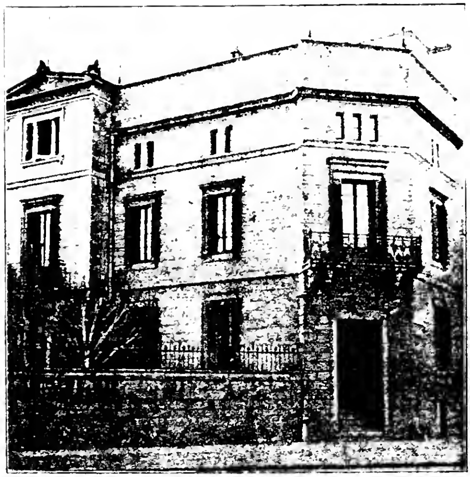


Figure #2: Guastavino Residence (1872), Barcelona, Spain, designed by Rafael Guastavino [Peter B. Wight, "The Works of Rafael Guastavino. Part I. As Architect," The Brickbuilder 10 (April 1901)4:79.]

Figure #3: Residence (1868), Barcelona, Spain, designed by Rafael Guastavino [Peter B. Wight, "The Works of Rafael Guastavino. Part I. As Architect," The Brickbuilder 10 (April 1901)4:81.]

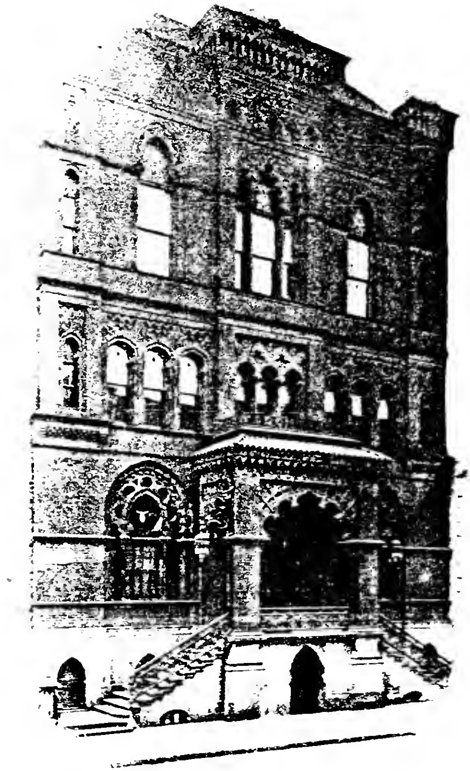


Figure #4: Progress Club (1883), New York City, designed by Rafael Guastavino in collaboration with Henry Fernbach [Peter B. Wight, "The Life and Works of Rafael Guastavino. Part II. What is Cohesive Construction," The Brickbuilder 10 (May 1901)5:100.]

Figure #5: Photograph of Load Capacity Test conducted in New York City in 1901 [Guastavino Archives (uncat.), Drawings and Archives, Avery Architectural and Fine Arts Library, Columbia University, New York.]

Figure #6: Photograph of Load Capacity Test conducted in New York City in 1901 [Guastavino Archives (uncat.), Drawings and Archives, Avery Architectural and Fine Arts Library, Columbia University, New York.]

p. 793 American Architect and Building News Feb 7 1891.

Guastavino Fireproof Construction Co.

MAIN OFFICE, 57TH STREET, NEAR 11TH AVENUE, NEW YORK.

BOSTON, MASS.

PROVIDENCE, R.I.

CHICAGO, ILL.

MILWAUKEE, WIS.

Buildings completed or in process of construction, in which the Guastavino Fireproof Construction Company or R. Guastavino has obtained contracts, and put in Fireproofing.

NEW YORK.	Sun Fire Company Building	New York
	Corbin Building	"
	Lyons Building, Bleecker Street	"
	Mt. Sinai Hospital	"
	Music Hall	"
	Arion Club	"
	Sidenberg Building	"
	Plaza Hotel	"
	Young Woman's Christian Ass'n Building	"
	" " Lodging House	"
	Manhattan Brass Foundry	"
	" " Extension	"
	Lyons Building, Mercer Street	"
	" " Waverly Place	"
	Lion Brewery	"
	Matthiessen Vaults	Woodlawn.
	Hammerstein Harlem Opera House	New York
	Fish Building	"
	Montauk Club	Brooklyn.
	Bloomingdale Building	New York
	LaConcha Baths	Syracuse.
	Norton Building	New York.
	Atlantic Brewery	Staten Island.
MASSACHUSETTS	Boston New Public Library	Boston.
	Exeter Chambers	"
	Grafton Building	"
	Boston Gas Light Company Building	"
	Bay State Gas Company Building	"
	Harcourt Building	"
	Cox Stable	Brookline.
	Savage Building	Boston.
	Massachusetts State House Extension	"
COLORADO.	Colorado Telephone Co's Building	Denver.
	Denver Athletic Club	"
NEW HAMPSHIRE.	Dover City Hall	Dover
	Hitchcock Memorial Hospital	Hanover
PENNSYLVANIA.	Philadelphia Market	Philadelphia.
RHODE ISLAND.	Morgan Stables	Newport.
NEW JERSEY.	W. Fellows' Residence	Montclair.

This Company gives Estimates and takes Contracts for Fireproof Buildings, Floors, Ceilings, Partitions and Staircases, under the system called, GUASTAVINO TILE ARCH SYSTEM.

The above list will show the increase of their business and general facilities.

Figure #7: Advertisement [American Architect and Building News 31 (March 7, 1891):pl. 793.]

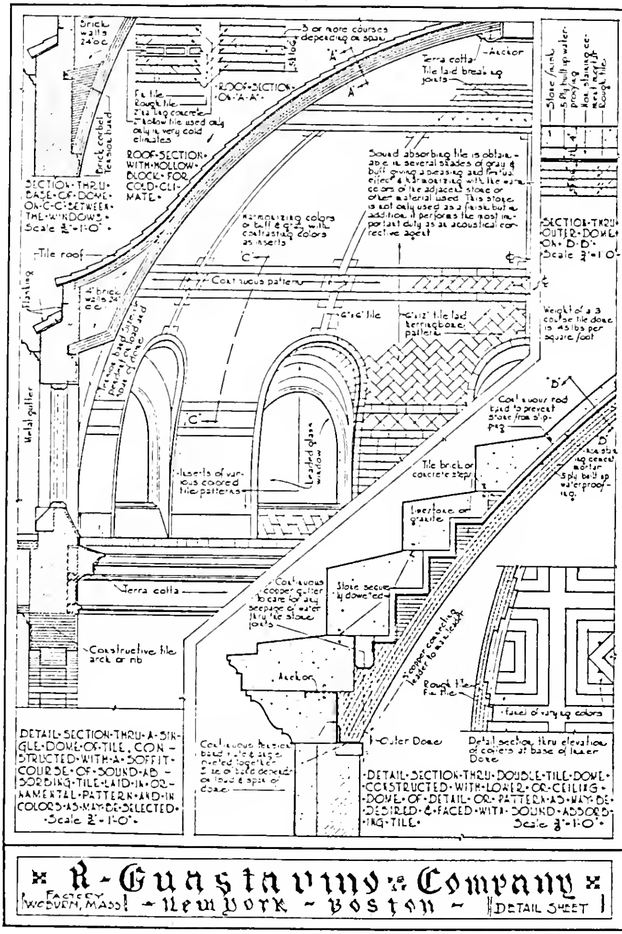


Figure #8: Detail Sheet, Domes [Guastavino Archives (uncat.), Drawings and Archives, Avery Architectural and Fine Arts Library, Columbia University, New York.]

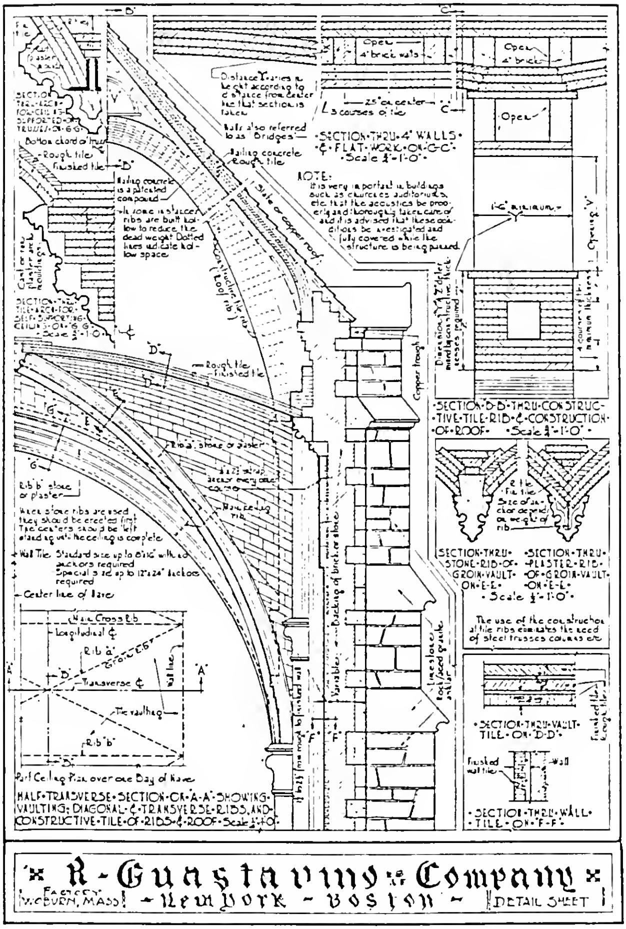


Figure #9: Detail Sheet, Vaults [Guastavino Archives (uncat.), Drawings and Archives, Avery Architectural and Fine Arts Library, Columbia University, New York.]

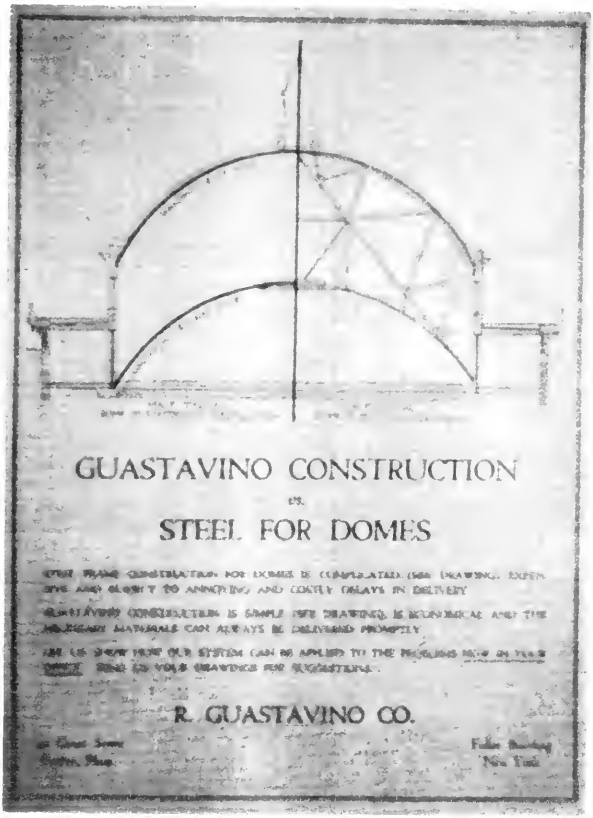


Figure #10: Advertisement [Guastavino Archives (uncat.), Drawings and Archives, Avery Architectural and Fine Arts Library, Columbia University, New York.]

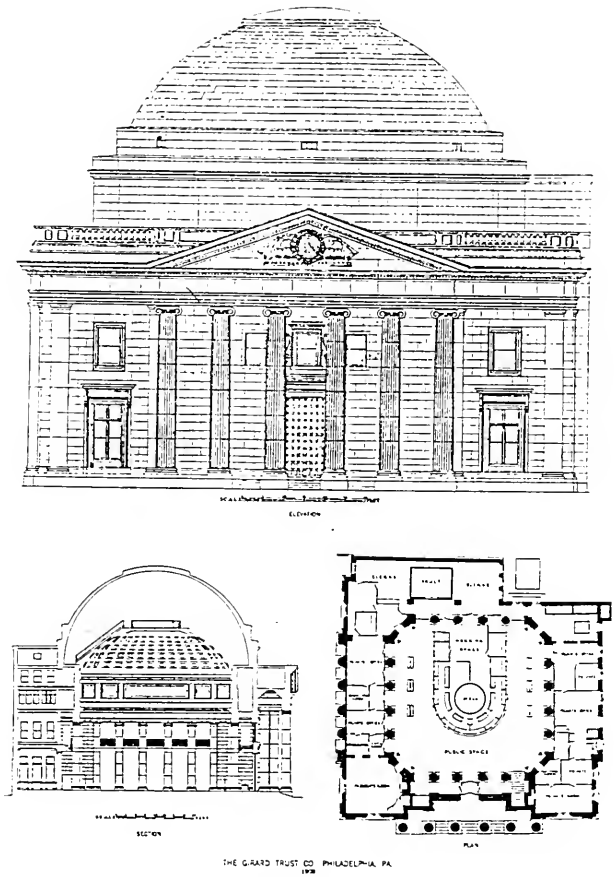


Figure #11: Girard Trust Bank: Plan, Section & Elevation [A Monograph of the Works of McKim, Mead & White: 1879-1915 (New York: Da Capo Press, Inc., 1985), pl. 330.]

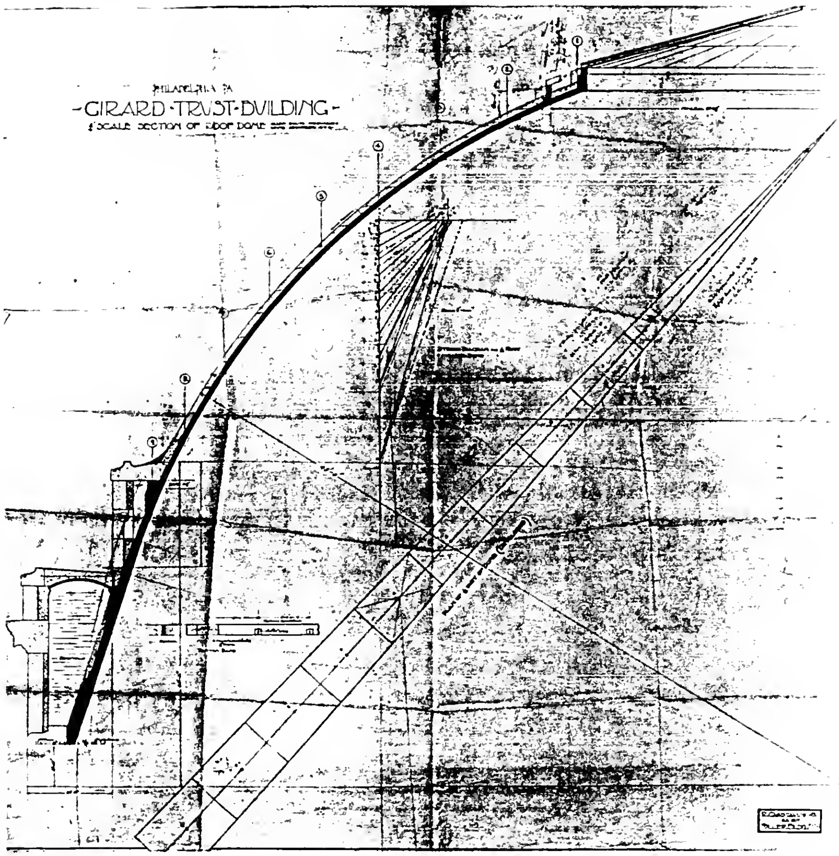


Figure #12: Girard Trust Bank: Section through Dome
[Guastavino Archives (uncat.), Drawings and Archives, Avery Architectural and Fine Arts Library, Columbia University, New York.]

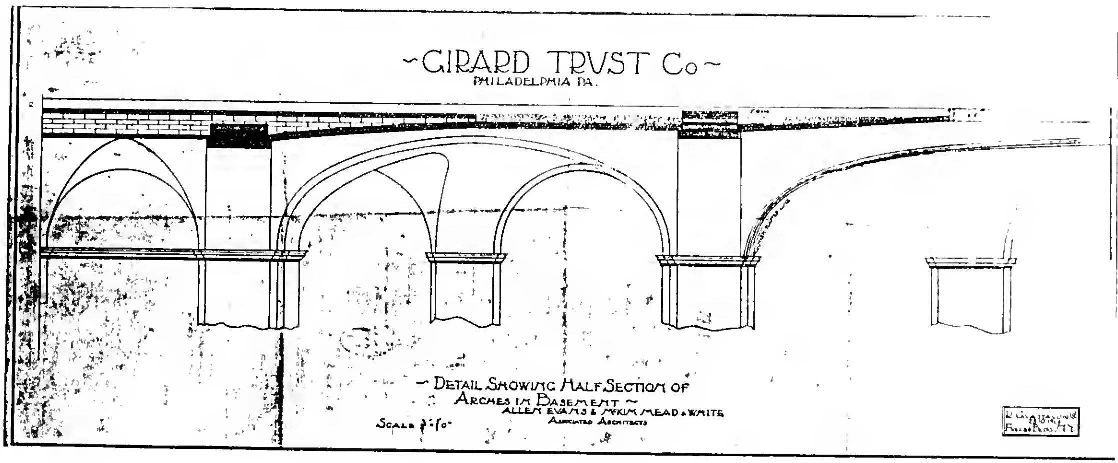


Figure #13: Girard Trust Bank: Section through Basement [Guastavino Archives (uncat.), Drawings and Archives, Avery Architectural and Fine Arts Library, Columbia University, New York.]

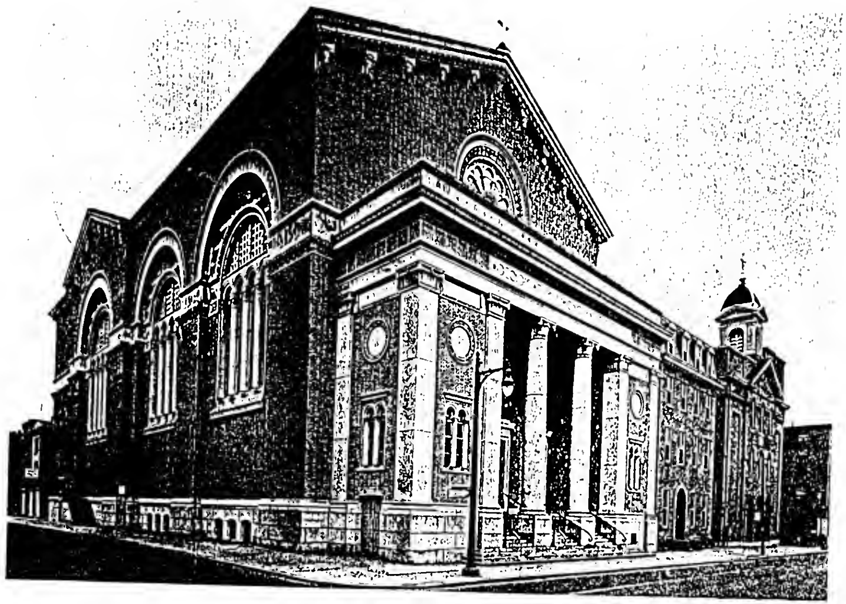


Figure #14: St. Patrick's Church: Exterior Photograph [A Century of Faith, Church of St. Patrick, 6.]

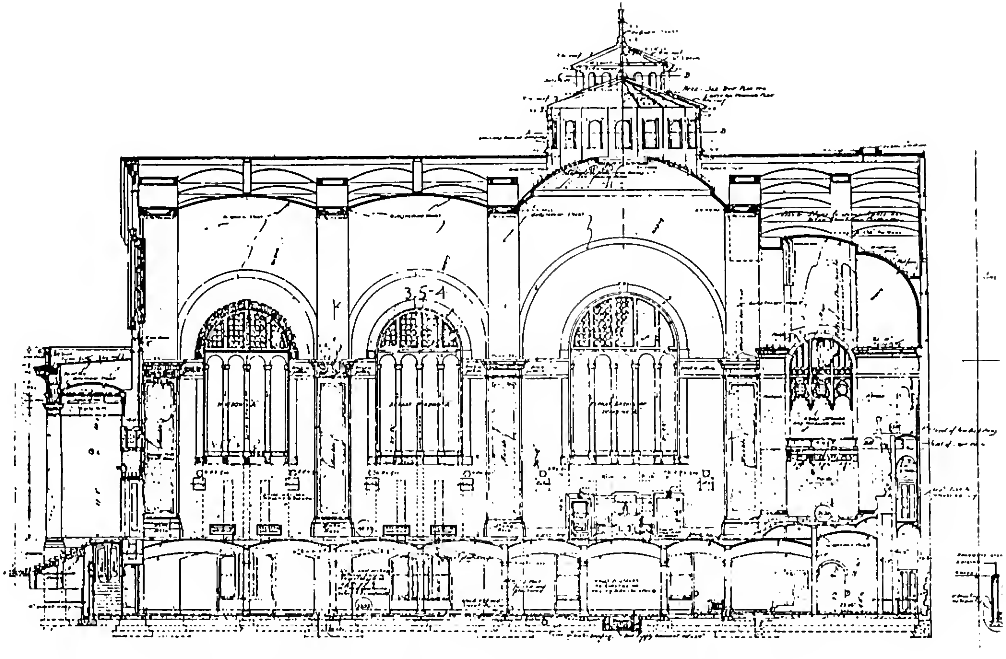


Figure #15: St. Patrick's Church: Longitudinal Section
[William E. Campbell, ...How unsearchable His Ways: One hundred Twenty-fifth Anniversary, St. Patrick's Parish, Philadelphia, 1965, 56.]

Figure #16: St. Patrick's Church: Interior Photograph of Main Sanctuary [William E. Campbell, ...How unsearchable His Ways: One hundred Twenty-fifth Anniversary, St. Patrick's Parish, Philadelphia, 1965, 56.]

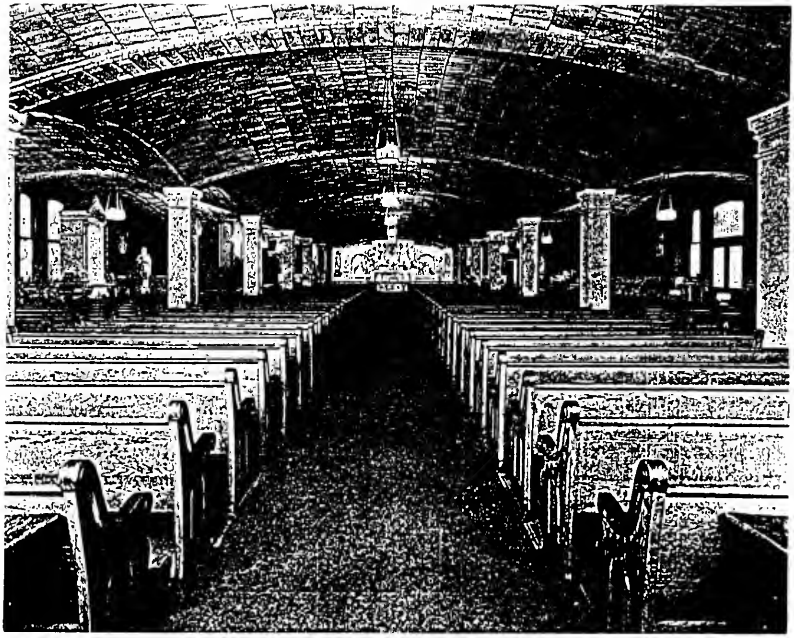


Figure #17: St. Patrick's Church: Interior Photograph of Lower Church [A Century of Faith, Church of St. Patrick, 6.]

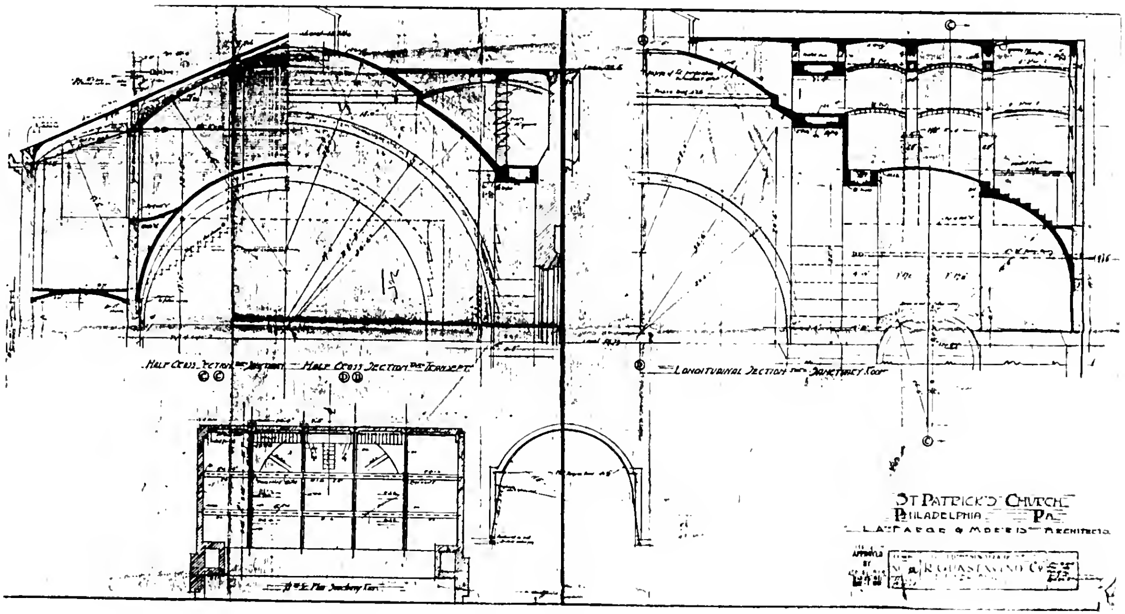


Figure #18: St. Patrick's Church: Details [Guastavino Archives (uncat.), Drawings and Archives, Avery Architectural and Fine Arts Library, Columbia University, New York.]

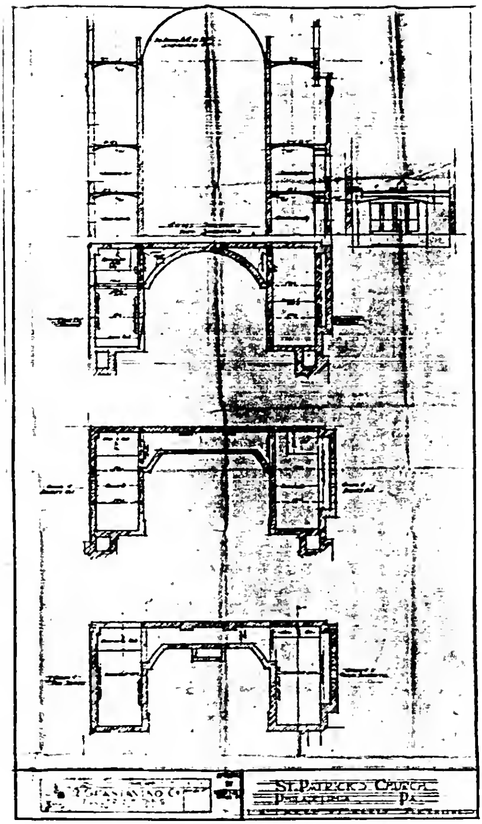


Figure #19: St. Patrick's Church: Sections [Guastavino Archives (uncat.), Drawings and Archives, Avery Architectural and Fine Arts Library, Columbia University, New York.]

Figure #20: St. Francis de Sales Church: Exterior Photograph
[Parish History Collection, Archives of the Catholic Diocese of Philadelphia, St. Charles Seminary, Philadelphia.]

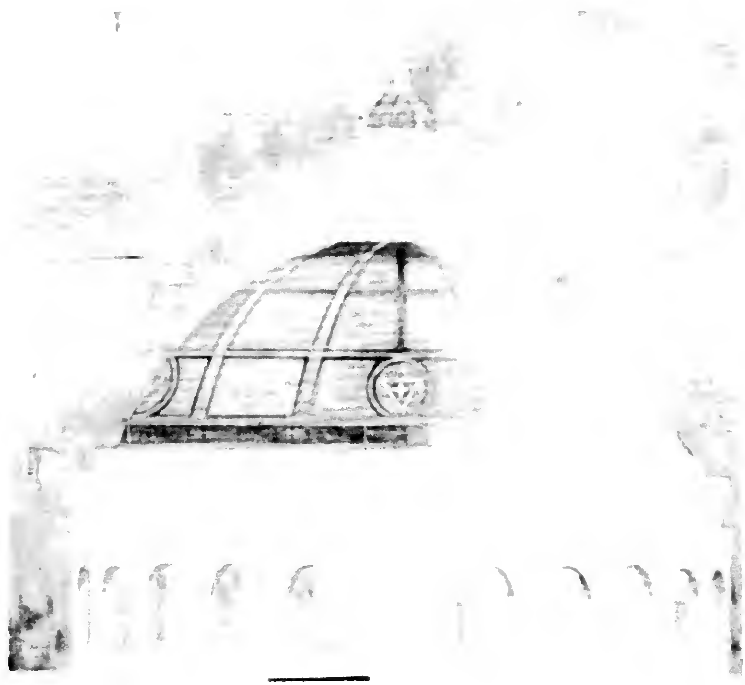


Figure #21: St. Francis de Sales Church: Dome Ornamentation Design [Guastavino Archives (uncat.), Drawings and Archives, Avery Architectural and Fine Arts Library, Columbia University, New York.]

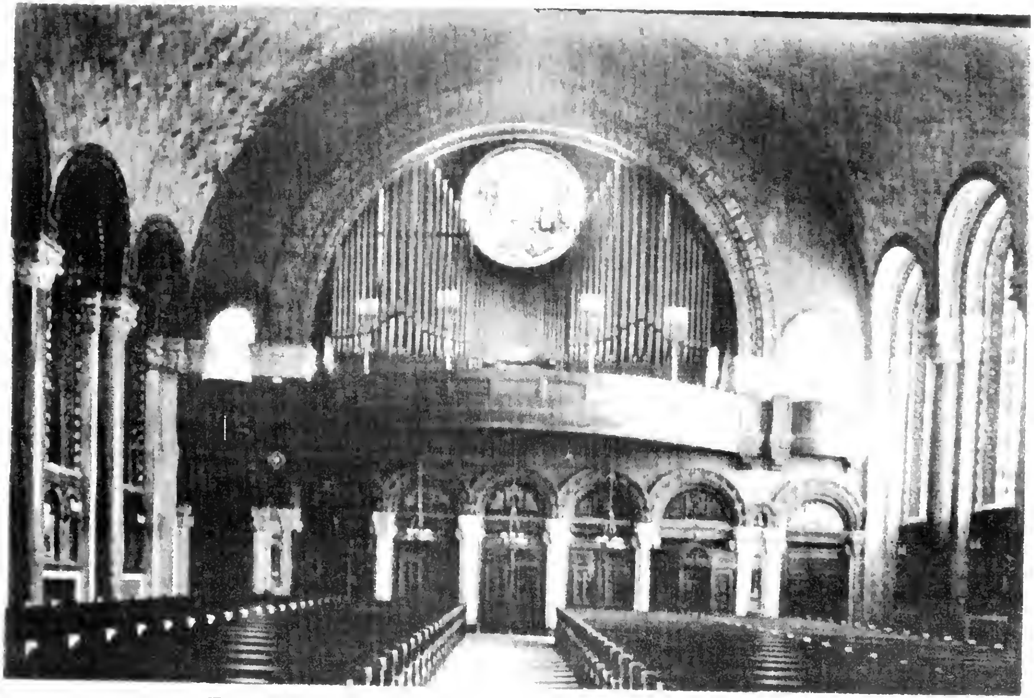


Figure #22: St. Francis de Sales Church: Interior Photograph [Guastavino Archives (uncat.), Drawings and Archives, Avery Architectural and Fine Arts Library, Columbia University, New York.]

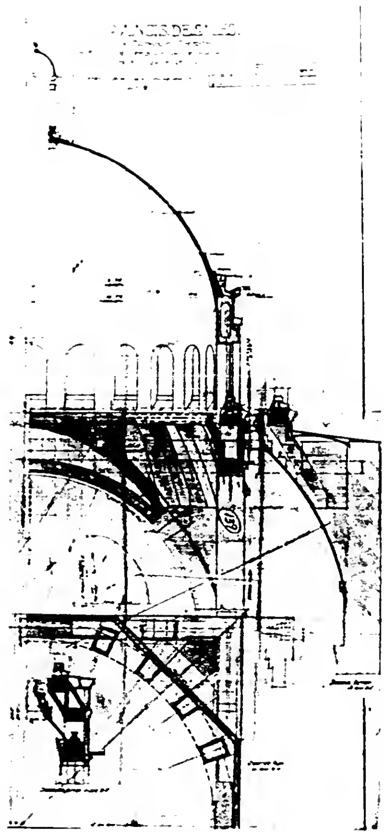


Figure #23: St. Francis de Sales Church: Section through Dome
[Guastavino Archives (uncat.), Drawings and Archives, Avery Architectural and Fine Arts Library, Columbia University, New York.]

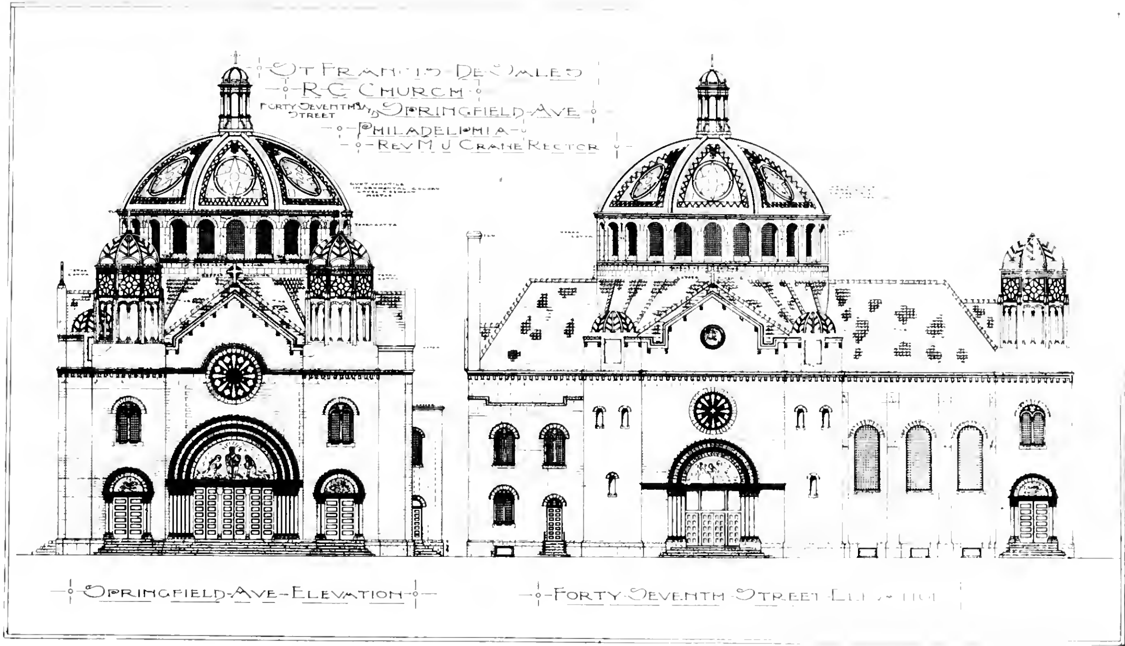


Figure #25: St. Francis de Sales Church: Preliminary Designs for the Street Elevations [Henry Dagit Collection, Architectural Archives, The Athenaeum of Philadelphia.]

Figure #27: University Museum, University of Pennsylvania: Section through Rotunda [Wilson Eyre Collection, Architectural Archives, Furness Fine Arts Library, University of Pennsylvania, Philadelphia.]

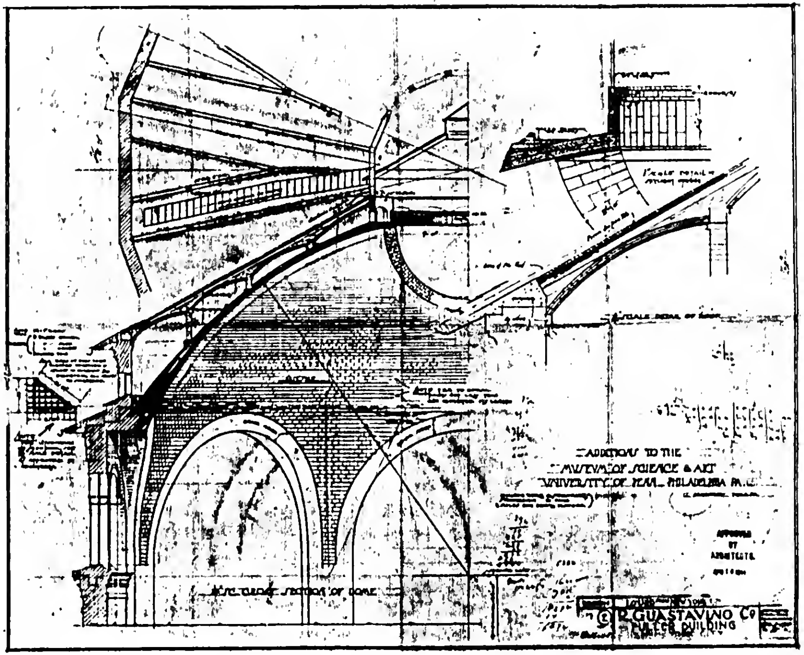


Figure #28: University Museum, University of Pennsylvania: Section through Rotunda Dome [Guastavino Archives (uncat.), Drawings and Archives, Avery Architectural and Fine Arts Library, Columbia University, New York.]

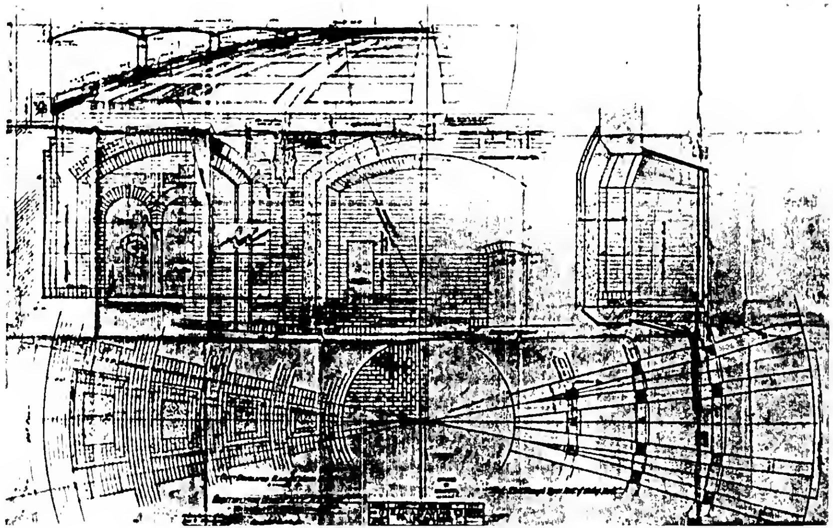


Figure #29: University Museum, University of Pennsylvania: Section through Auditorium Vault [Guastavino Archives (uncat.), Drawings and Archives, Avery Architectural and Fine Arts Library, Columbia University, New York.]

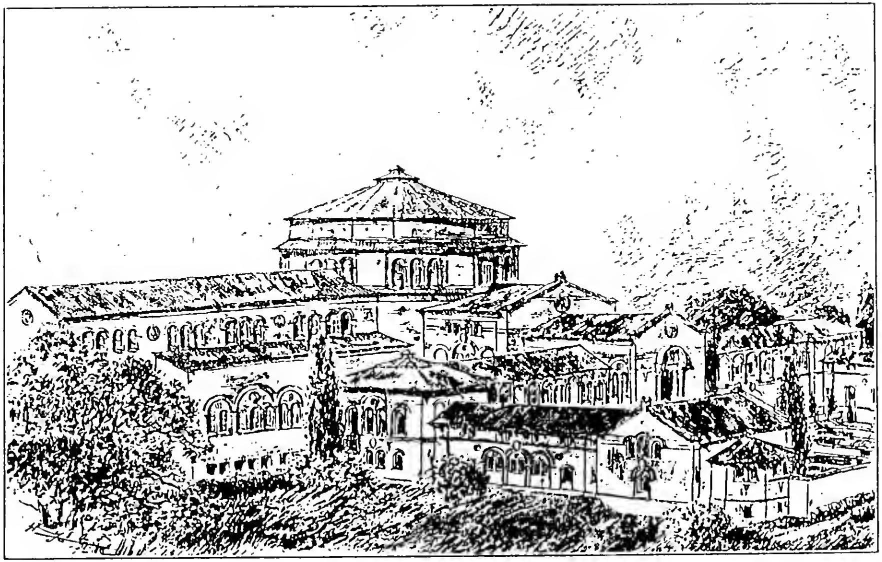


Figure #30: University Museum, University of Pennsylvania: Axonometric Sketch [The Museum Journal XV (December 1924)4:pl. III.]

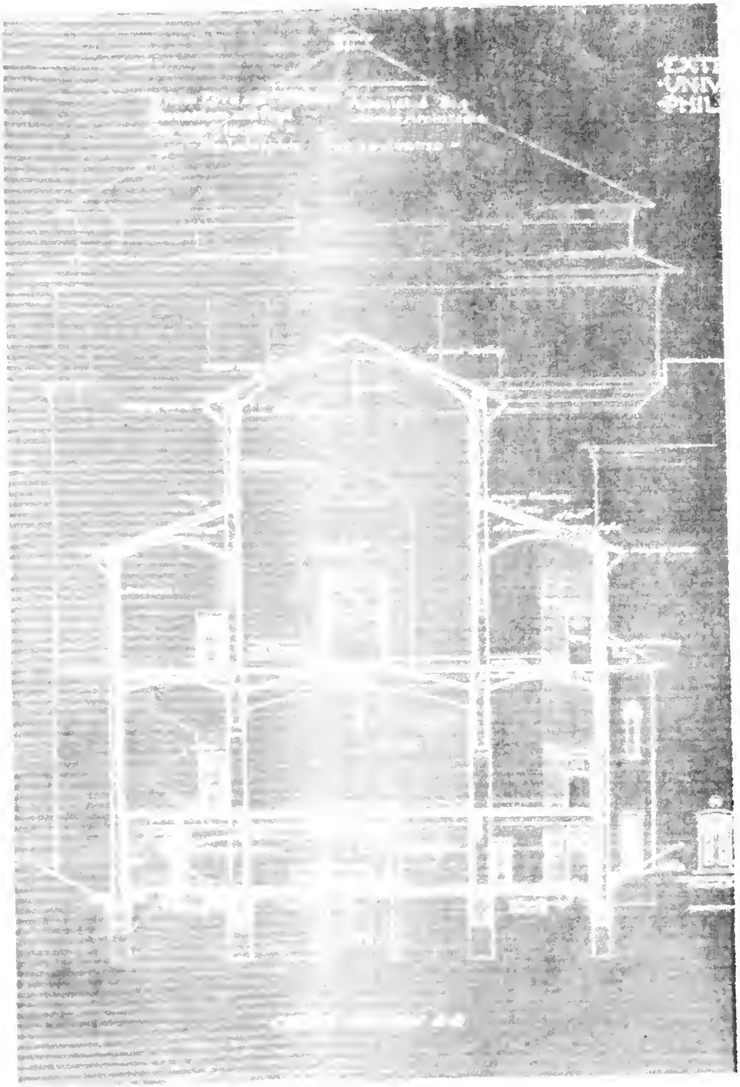
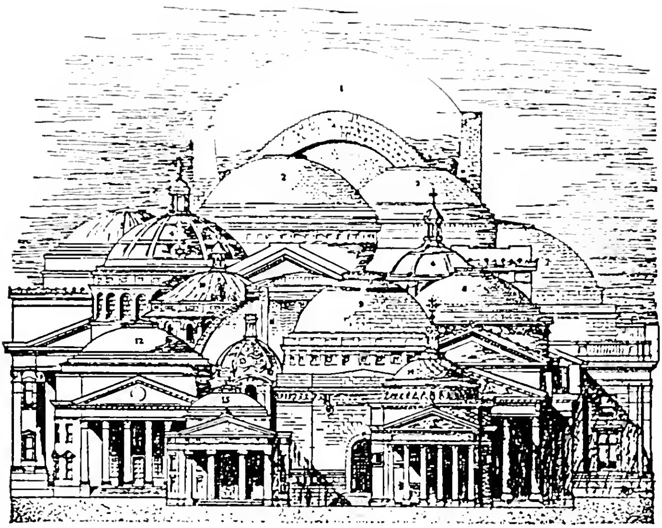


Figure #31: University Museum, University of Pennsylvania: Cross Section through Egyptian Wing [Wilson Eyre Collection, Architectural Archives, Furness Fine Arts Library, University of Pennsylvania, Philadelphia.]



Some Domes Constructed by R. Guastavino Company

	BUILDING AND LOCATION	SPAN	ARCHITECT
1.	Cathedral, St. John the Divine, New York, N. Y.	135 ft. at base	Heins & La Farge
2.	National Museum, Washington, D. C. ..	80 " " "	Hornblower & Marshall
3.	Institute of Arts and Sciences, Brooklyn, N. Y. ..	64 " " "	McKim, Mead & White
4.	St. Francis de Sales Church, Philadelphia, Pa.	61 " " "	Henry D. Dagit
5.	Bank of Montreal, Montreal, Can. .	69 " " "	McKim, Mead & White and A. T. Taylor
6.	Church of St. Barbara, Brooklyn, N. Y.	43 " " "	Helmle & Huberty
7.	Girard Trust Co., Philadelphia, Pa. ..	101 " " "	McKim, Mead & White and Allen Evans
8.	University of New York, New York, N. Y. ..	70 " " "	McKim, Mead & White
9.	McKinley National Memorial, Canton, Ohio	56 " " "	H. Van Buren Magonigle
10.	St. Paul's Chapel, Columbia University, New York, N. Y.	52 " " "	Howells & Stokes
11.	Rodef Shalom Synagogue, Pittsburgh, Pa.	60 " " "	Palmer & Hornbostel
12.	University of Virginia, Charlottesville, Va.	70 " " "	McKim, Mead & White
13.	Elephant House, Bronx Park, New York, N. Y.	34 " " "	Heins & La Farge
14.	Madison Square Presbyterian Church, New York, N. Y.	45 " " "	McKim, Mead & White
15.	J. J. Jermain Memorial Library, Sag Harbor, N. Y.	50 " " "	Augustus N. Allen

Figure #32: Advertisement [Sweet's Catalogue of Building Construction, 17th ed. (New York: Architectural Record Company, 1922), 19.]